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Fourth Sanitary Engineering Conference

WATER DISTRIBUTION SYSTEMS

conducted by the

ILLINOIS STATE DEPARTMENT OF PUBLIC HEALTH

and the

UNIVERSITY OF ILLINOIS

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IN COOPERATION WITH THE

Division of University Extension

FEBRUARY 13-14, 1962

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The Committee gratefully acknowledges the cooperation and assistance of Mr. R. K. Newton of the Division of University Extension in making arrangement for the conference and the assistance of the staff of the Engineering Publication Office of the University of Illinois Engineering Experiment Station in publishing these proceedings.

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INTRODUCTION

An analogy can be drawn between the intent of the Fourth Sanitary Engineering Conference and *Water Distribution Systems,* its theme. Each is designed to provide a means for the delivery of a product. The results of research and operating experience are the sources of supply for the Conference. Pumping is provided by those experimenters and investigators who report on their observations. The consumers are those who stand ready to receive new ideas and information. The consumers of these ideas, in turn, bear the responsibility for the beneficial application of these ideas. Ultimately, the evaluation of such a distribution system depends on its net effect in transporting the products of research and operating experience to a useful application.

In any distribution system, there is a limitation upon supply; sometimes in the source, sometimes in the pumping capacity, often in the distribution system. The Illinois Department of Public Health, Sanitary Engineering Division, and the University of Illinois, Department of Civil Engineering, co-sponsors of the Sanitary Engineering Conference, are vitally interested in maintaining and improving the capacity, and thereby the net effect, of this distribution system.

There is an axiom in the waterworks field; the supply must meet the demand. Correspondingly, the results of pertinent experiments and observations made by operators, engineers, and sanitary scientists must be disseminated and put to useful ends.

The Conference Committee would like to praise the speakers for their excellent performance. Equally important, the Committee wishes to express its gratitude to the consumers, unquestionably the Conference's most vital element. It is hoped they will return, either again as consumers or as suppliers. Finally, the Committee feels great pride in being able to serve as part of the distribution system for what it considers to be one of the most important products in modern-day technology.

Conference Committee

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HYDRAULICS OF WATER DISTRIBUTION SYSTEMS

Carl W. Reh[1]

INTRODUCTION

The purpose of a water distribution system is to provide adequate quantities of water to all users, for all purposes, at all times and at reasonable pressure. Water distribution systems comprise pumping stations, pipe systems, storage facilities, blowoffs, house connections, fire hydrants, surge protection devices, and other appurtenances. In various ways, all of these elements are involved in distribution system hydraulics and all are largely interdependent. This paper will discuss the fundamentals of distribution system hydraulics and some applications of these fundamentals to design.

FUNDAMENTAL CONSIDERATIONS

Fundamental to the hydraulic design of water distribution systems are the following:

a. Rates of water consumption.
b. Distribution of water consumption.
c. Pressure gradients throughout the system.

Rates of Water Consumption

Water consumption for usual residential, commercial and industrial uses varies widely with the type and location of a community. The rates of water consumption for two midwestern communities are given in Table 1.

The hourly variation in water consumption for these two communities is shown on Figure 1.

Oak Park, Illinois, is a stable, Chicago suburban community almost entirely residential in character. It has experienced little change in population in the last decade. The village has a large, well developed commercial district, but virtually no industrial property.

Sioux Falls, South Dakota, however, might be called an independent city. It has large industrial areas, including a large packing plant, well developed commercial areas and has experienced a considerable increase in population in the last decade. The large increase in water consumption between the hours of 6:00 and 7:00 p.m. (see Figure 1) is not an isolated occurrence. It has been observed on numerous "maximum day" charts, in the city, and probably results from a combination of packinghouse operations and normal domestic operations associated with the preparation of the evening meal.

Table 1

Rates of Water Consumption for Sioux Falls, S.D., and Oak Park, Illinois

	Sioux Falls, S.D.		Oak Park, Ill.	
	MGD	% of An. Av.	MGD	% of An. Av.
Annual Average	8.3	100.	6.5	100.
Maximum Day	20.5	248.	10.0	155.
Maximum Hour	34.9	420.	15.0	232.

In comparing the hourly variation in consumption in these two dissimilar communities, it is interesting to note that the minimum hourly rate of water consumption is about identical.

Sioux Falls has considerable elevated storage. The rate of pumping remains fairly constant from 8:00 a.m. to 9:00 p.m., but the supply from the elevated tanks increases sharply to supply the maximum hour rate of water consumption. This is shown on Figure 2. The maximum rate from the elevated tanks was about 29 per cent of the maximum rate from the pumping station.

Great variations between annual average and maximum hour water consumption have been reported. Henderson(1)* reports ranges for small communities between annual average and maximum hour water consumption of 4.0 and 10.0. He also makes the following observation:

> As the community grows older, [the] lavish use of water on lawns and gardens reduces of itself. For instance, the peak demand at Levittown, Pa., occurred when about half of the 17,000 homes were built and occupied. The same hourly peak has never again been reached, even though a serious drought occurred during a late summer when approximately 15,000 homes were occupied.

Fire protection requirements are significant.

[1] Partner, Greeley and Hansen Consulting Engineers, Chicago 4, Illinois.

* Superscript numbers in parenthesis refer to References.

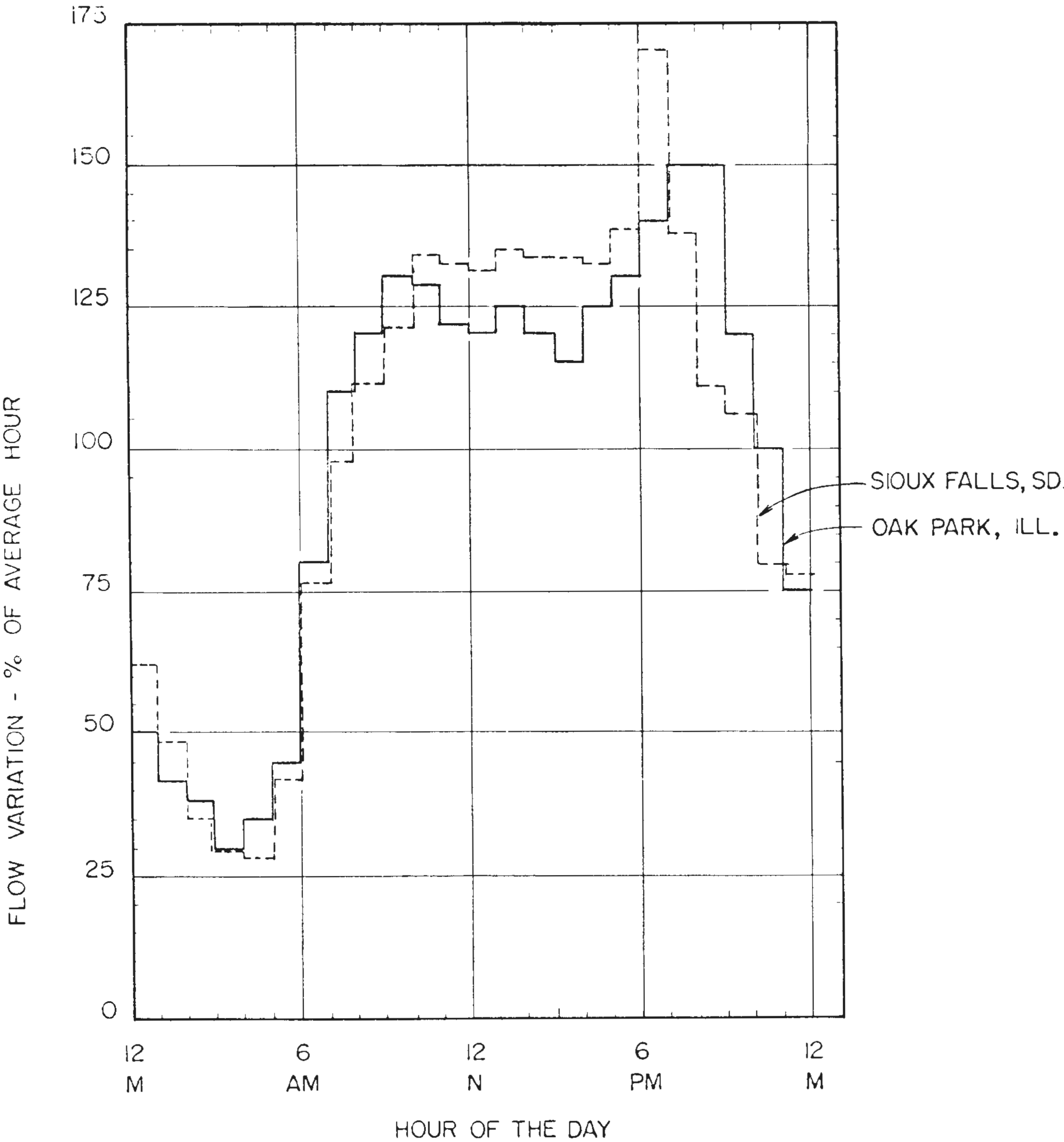

Figure 1. Hourly variation in water consumption for Sioux Falls, S.D., and Oak Park, Illinois

The formula recommended by the National Board of Fire Underwriters for estimating fire protection requirements is as follows:

$$Q = 1{,}020 \sqrt{P}\ [1\text{-}0.01 \sqrt{P}]$$

where: Q is the rate of fire flow in GPM, and
P is the population in thousands.

This formula is considered applicable to communities with populations up to 200,000 persons. For larger populations, additional quantities are required for a second fire.

The fire flow is usually considered to be added to the maximum day rate. The maximum rates of water consumption for the two communities mentioned previously are shown in Table 2.

The fire flows reported in Table 2 are those

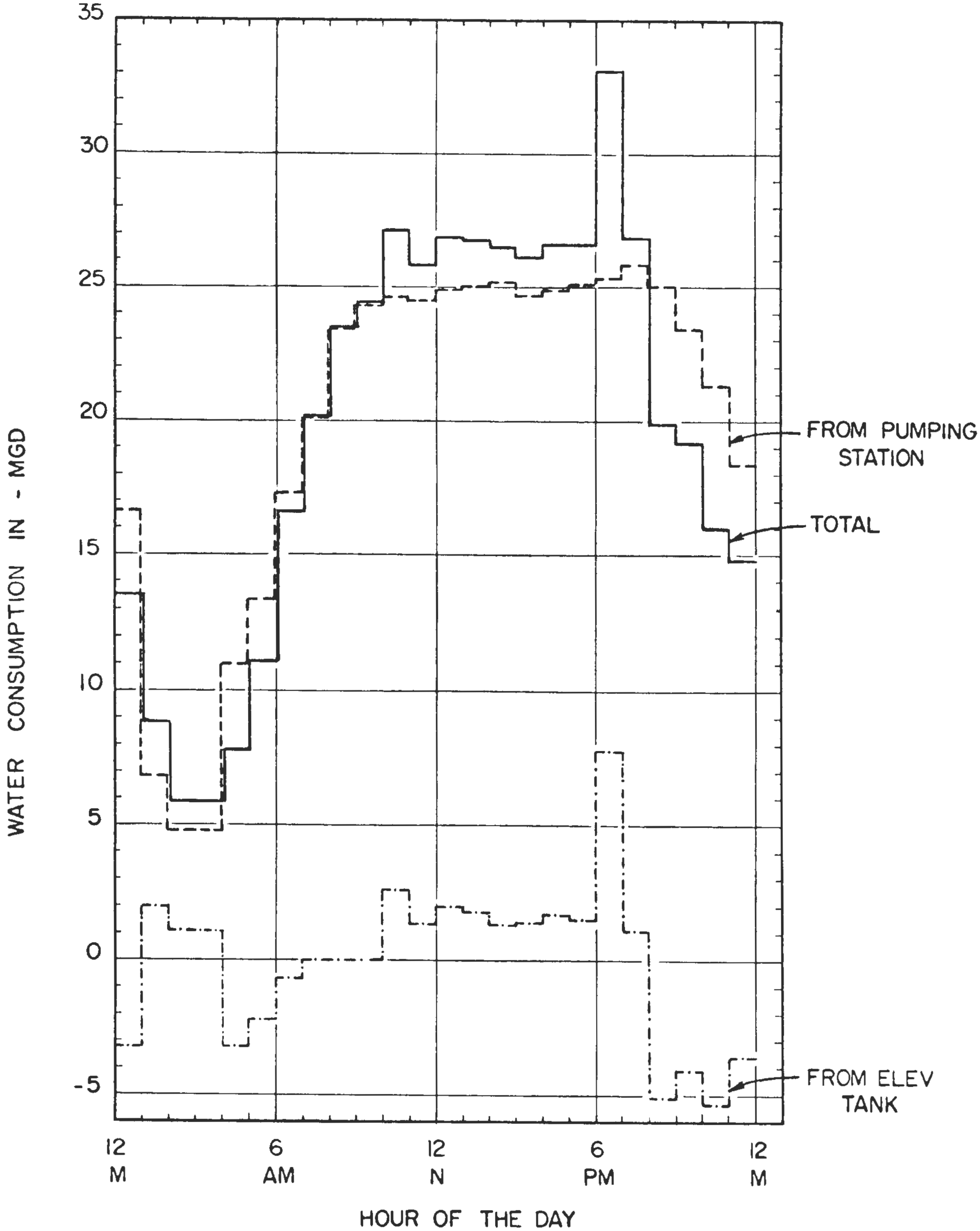

Figure 2. Hourly variation in water consumption and pumping

Table 2

Maximum Rates of Water Consumption for Sioux Falls, S.D., and Oak Park, Illinois

	Sioux Falls, S.D.	Oak Park, Ill.
Population (1960)	68,965	61,093
Water Consumption MGD		
Maximum Day	20.5	10.0
Fire Flow	11.0	10.4
Total	31.5	20.4
Maximum Hour	34.9	15.0

computed by the National Board of Fire Underwriters formula and not necessarily the quantities required by fire inspection bureaus.

For communities of the size of Sioux Falls and larger, the maximum hour rate of water consumption may exceed the maximum day rate plus fire protection requirements. This, however, does not necessarily indicate that the maximum hour rate will govern the design of the distribution system. The location of the principal fire hazard with reference to the source of water supply is important. As the principal fire hazard becomes more remote from the principal source of water supply, the more likely it becomes that the maximum day rate plus fire flows will govern the design of the pipe network. Both conditions should be investigated.

Distribution of Consumption

Records of total water consumption are usually readily available and amenable to analysis, but distribution of consumption during periods of maximum use must be estimated.

Where large industrial or commercial areas appear to have a significant effect upon the pattern of distribution of consumption, investigation of the hourly variation of water consumption in separate areas may be warranted. Otherwise, the assumption is made that the variation in consumption in all areas of the community is proportional to the total.

Where the rate of water consumption by large industrial or commercial users appears to warrant further consideration, field determination of hourly variation is usually necessary. Study of the operation of these users may be sufficient, but where the industrial consumption is large enough to warrant special consideration, observations on the actual hourly variation in consumption are desirable.

Consumption throughout the system can be estimated by analysis of water meter book records, or distribution of population from census tracts, precincts, or other population records. The water consumption, estimated on these bases, is usually concentrated at selected points on the trunk main system. In a recent paper, Muss[2] suggests a method by which the effects of multiple take-offs along a pipe line may be estimated, but the computations with concentration of consumption at points on the trunk main system show good correlation with field observations. From observations and computations on the Philadelphia system, McPherson[3] reports, " . . . these same estimations and assumptions lead to calculated head losses for a class of existing networks which usually agree remarkably well with field system head loss measurements."

Pressure

Distribution systems should be designed to maintain fairly uniform pressures. During a major conflagration, it may not be objectionable to permit the pressure in the vicinity of the fire to drop to 20 p.s.i., and perhaps slightly lower, but for all other conditions, the minimum pressure should be 30 p.s.i. Pressures between 40 p.s.i. and 75 p.s.i in the trunk main system are desirable. Although pressures in excess of 75 p.s.i. may be satisfactory, some difficulty may be experienced with household water heaters if higher pressures are experienced. Pressure relief valves are frequently set at 75 p.s.i.

Few areas are of such size or so level that the effects of elevation differences can be ignored. Even in the State of Florida, which is probably as level as any state in the Union, changes in elevation in excess of 30 feet in a single community are not unusual.

PIPE NETWORK ANALYSIS

Pipe Flow Formulas

Many pipe flow formulas are available, but the formula which appears to be most widely used for pipe networks is the Williams-Hazen formula. This formula, usually written:

$$V = 1.318\, C\, R^{0.63}\, S^{0.54},$$

where V = velocity in f.p.s
S = hydraulic gradient
R = Hydraulic radius in feet
C = friction coefficient,

also may be written in the form

$$h = kQ^{1.85}$$

where h = head loss in feet
k = constant
Q = quantity.

In this latter form it may be used for computer analyses as well as for manual computations. Further, many tables have been prepared using this formula. Williams-Hazen slide rules are also available.

The friction factor "C" is determined empirically. A value considered to be average is 100, but variations from 50 to 150 have been observed on test. New cast iron or steel pipe may have a "C" of 130 or higher, but unless the metal is protected by an adequate coating, the coefficient may deteriorate rapidly. The importance of maintaining "C" is illustrated in Table 3.

Table 3

Effect of "C" Values on the Carrying Capacity of Pipes

"C"	Diameter in Inches for Uniform Capacity (Read Down)					
130	30"	24"	20"	18"	16"	12"
120	31.0	24.8	20.6	18.6	16.5	12.4
110	32.0	25.6	21.3	19.2	17.1	12.8
100	33.2	26.5	22.1	20.0	17.7	13.3
90	34.5	27.6	23.0	20.7	18.4	13.8
80	36.0	28.9	24.0	21.7	19.3	14.5

Cement lining or concrete pipe is subject to some deterioration of "C," but it appears to proceed at a slower rate. A 36-inch concrete pipe line installed in 1930 was reported to have a "C" of about 155. In a test conducted in 1950, "C" was calculated to be about 130. In a test in 1961, "C" appeared to be about 125. The original design was based on $C = 130$. The loss in capacity over a 30-year period, therefore, has been quite nominal.

Miscellaneous losses for fittings and valves are usually disregarded in distribution system analyses. This appears reasonable, primarily for three reasons, as follows:

1. The distribution system for purposes of analysis is usually reduced to trunk mains and the capacity of the small mains neglected. This assumption produces conservative design.
2. Because of low velocities in trunk mains, rarely in excess of 4 f.p.s., the losses resulting from fittings are apt to be quite small.
3. Coefficients of friction determined by flow tests automatically compensate for the effects of fittings and valves.

Skeleton Systems

Whether analyzed by system analyzers or manual methods, distribution systems are reduced to trunk main or skeleton systems to simplify the analyses. The results of such analyses usually produce results consistent with field observations where the trunk main system has large capacity with reference to the smaller service mains. However, where no strong trunk main system exists, the reduction of a system to a skeleton system may produce erroneous results. A portion of an existing distribution system comprised largely of small mains was analyzed in three ways, as follows:

1. All mains considered.
2. The 6-inch mains grouped and considered as larger mains.
3. Only those mains 8 inches and larger considered.

The results of these analyses are shown on Figures 3, 4, and 5, respectively. The following will be noted:

1. Grouping of mains results in lower head losses than results from the consideration of all of the mains. The indicated head loss from grouping is about 58 per cent of the head loss of that which was computed with all mains considered.
2. The elimination of all mains 6 inches and smaller results in greater head loss and some rearrangement of the pattern of head loss. The indicated head loss when only the mains 8 inches and larger are considered is about 142 per cent of that computed with all mains considered.

When systems such as this are encountered, the characteristics of the system may be determined better by pressure observations and a few flow tests. The use of the proportional flow method outlined by McPherson[3] may be used to great advantage in systems of this type. Any form of skeleton system to be used for network analysis for this type of system without flow tests is apt to produce errors in which neither the direction nor magnitude can be accurately estimated.

Network Analysis

The Hardy Cross method of distribution system analysis is widely used for both manual methods and for digital computers. The method is

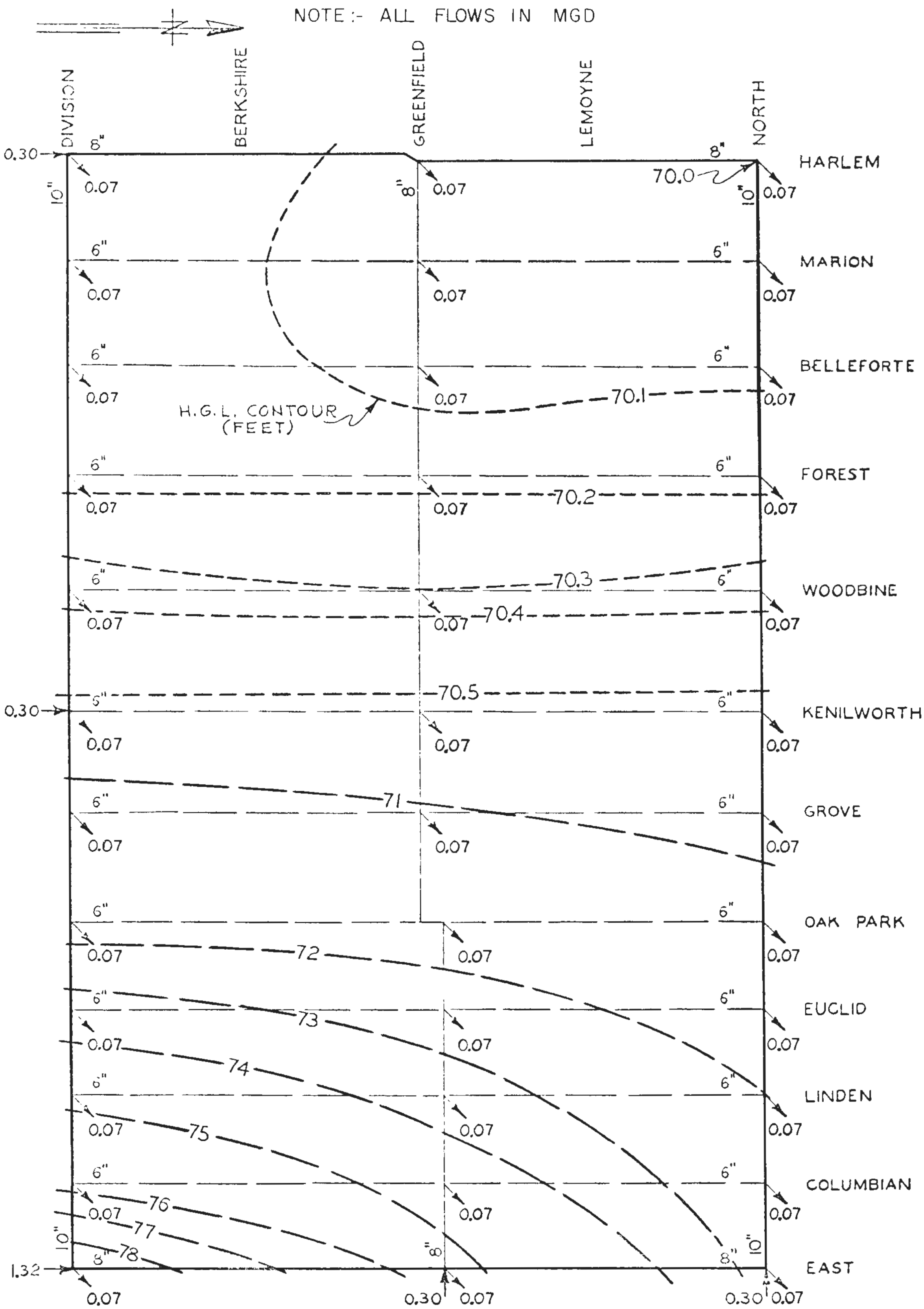

Figure 3. Distribution system analysis (all mains considered)

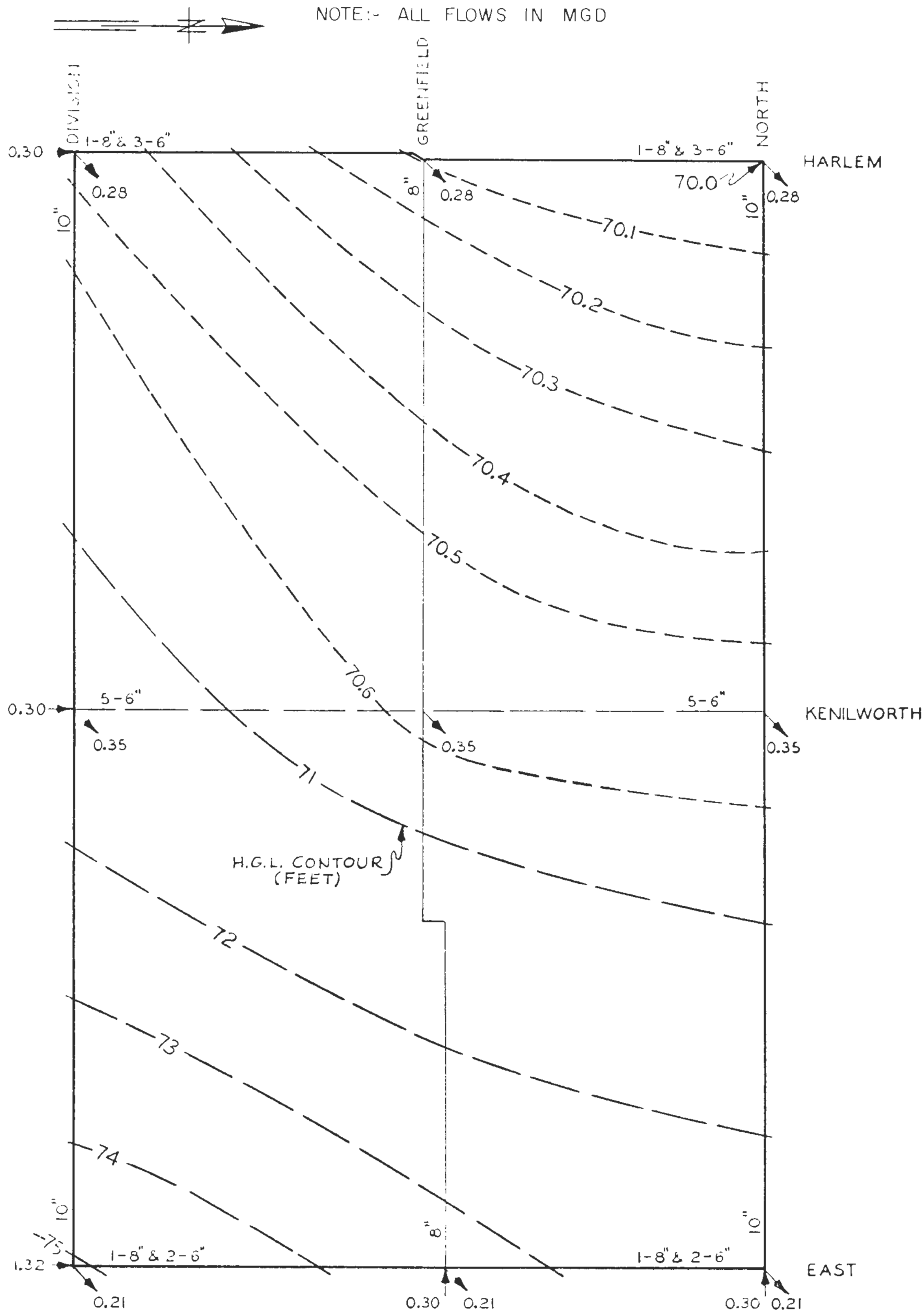

Figure 4. Distribution system analysis (6-inch mains grouped into larger equivalent mains)

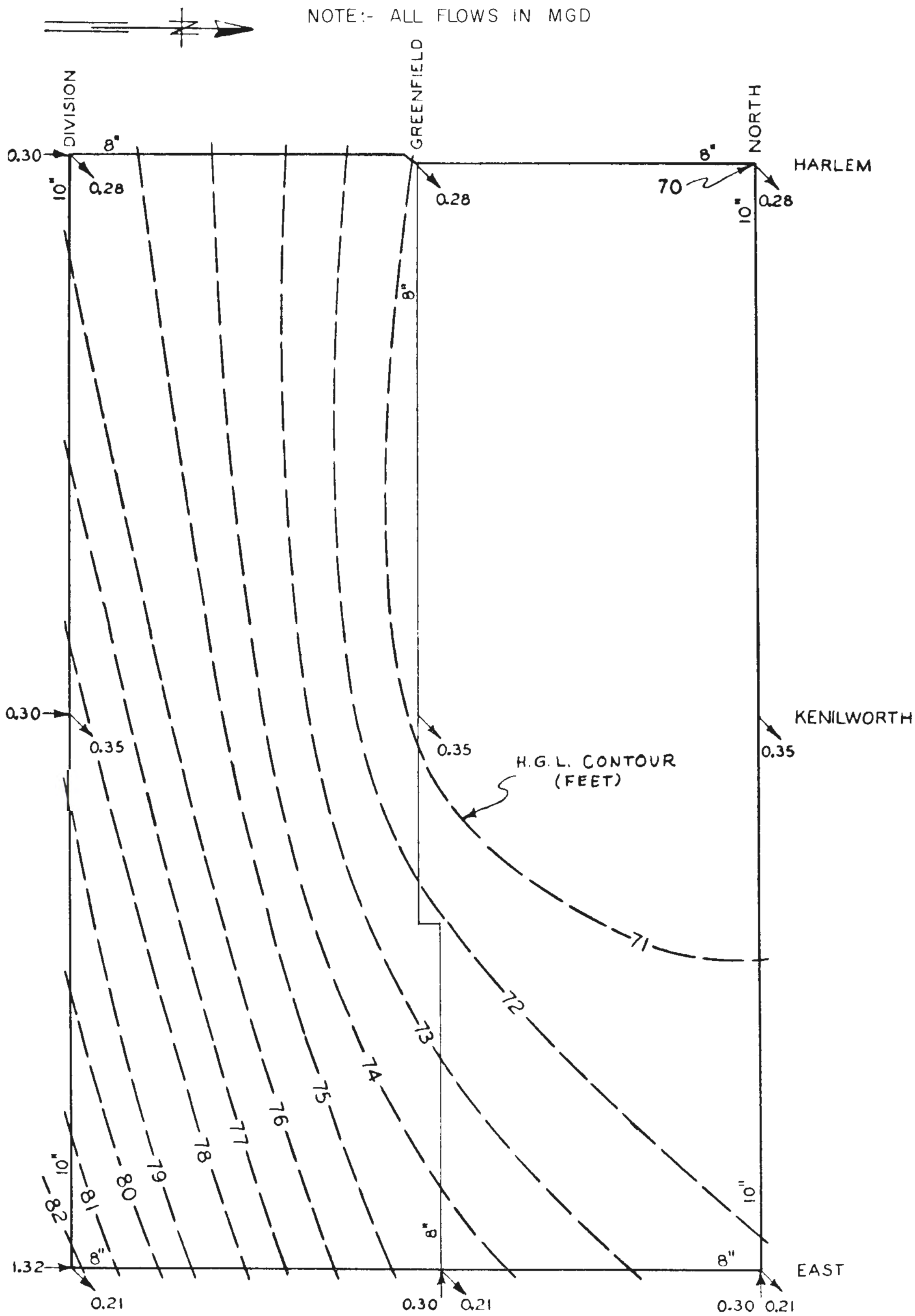

Figure 5. Distribution system analysis (mains 8 inches and larger considered)

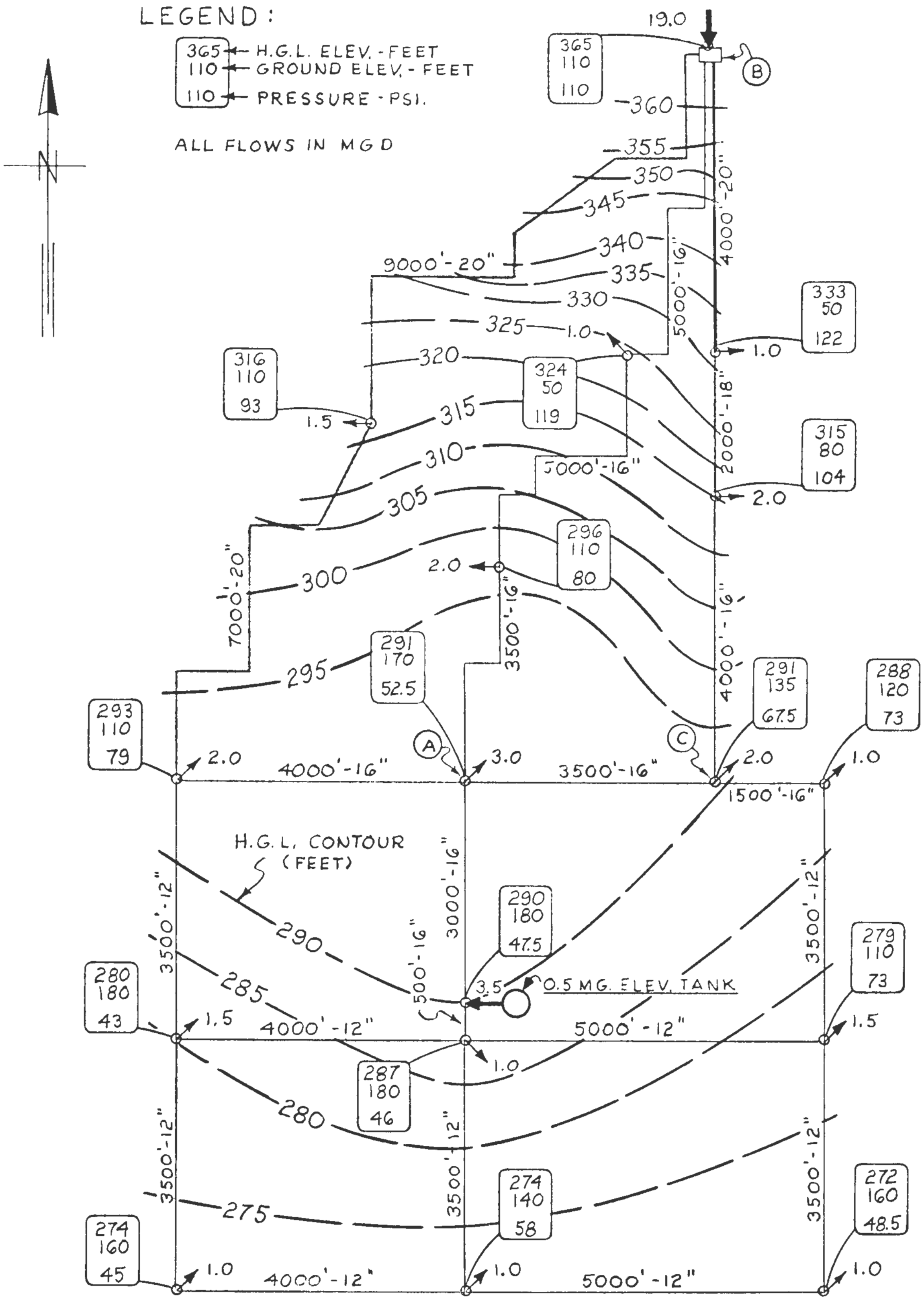

Figure 6. Distribution system analysis (illustrated system)

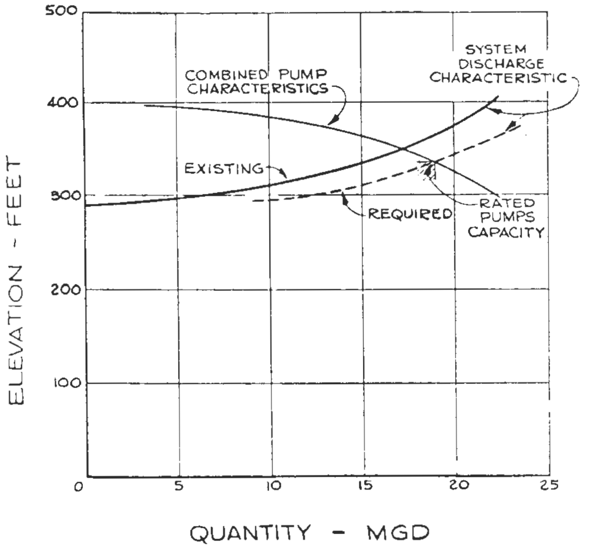

Figure 7. Pumping capacity and system discharge characteristic

basically one of successive approximations and is described in many standard texts.

In usual practice, the distribution of consumption is estimated and the deficiencies are noted. Additional mains are added and the system is again checked. A system analyzed for the maximum hour water consumption by this method is shown on Figure 6. Flow into the system is derived from a pumping station and from one elevated tank. The hydraulic grade line at the pumping station is about Elevation 365.

The pumping station performance is shown on Figure 7. It will be noted that the system head is such that the required water consumption cannot be supplied by the pumps. The maximum HGL is Elevation 336, while the computed system HGL at the pumping station for a capacity of 19.0 MGD (million gallons per day) is 365. The construction of an additional main between points A and B, shown on Figure 6, would reduce the HGL at the pumping station, but may alter the pattern of distribution. A procedure for estimating the size of a parallel main is as follows:

The allowable head loss between points A and B is 336′ − 290′ = 46 feet.

$$h_f = kQ^{1.85}$$

Head loss for $Q = 19.0$ MGD = 75′

Compute Q_1 for $h_f = 46'$ through existing system.

By proportional flow:

$$Q_1^{1.85} = \frac{46}{75}(19.0)^{1.85}$$

$$Q_1 = 15.0 \text{ MGD}$$

Thus, the additional main to supply 19.0 − 15.0 = 4.0 MGD from points A to B with a head loss of 46′, a total length of 13,500 feet and C = 100, is about a 19-inch diameter main. The analysis with a 20-inch main paralleling the main between points A and B is shown on Figure 8. It will be noted that the HGL at Point B, the pumping station is within satisfactory limits.

A recent paper in the *Journal of the American Water Works Association* suggests an automatic method for determining distribution system improvements.[4] In this method, the desirable HGL is estimated and the system is analyzed to produce this HGL. The procedure follows that of the Hardy Cross method, with the exception that the system is balanced for Q to determine required pipe diameters to produce the desired HGL. The system shown on Figures 6 and 8 was analyzed by the method suggested by Tong.[4] The calculated improvements are shown on Figure 9. This analysis shows that several of the mains would require additions, but several appear to have excess capacity. The remaining steps required to complete the analysis are (1) the sizing of mains to be added to the system and (2) checking the entire systems by a Hardy Cross analysis.

The method proposed by Tong,[4] appears to have the advantage of pinpointing by "automatic" methods the areas of inadequate capacity, but the method does not provide "automatic design." It does provide a useful tool for major augmentation of the trunk main system. A situation for which this method may be quite useful is outlined as follows:

> A community requires the addition of trunk mains for present and expected future water consumption. The general location of these trunk mains is fairly well defined and supplementary loops can be established. The size of the main and the date of construction have not been determined.

For this type of situation, the length and location of the supplementary mains can be included in the first analysis of the system. The size of the supplementary mains is then determined more or less automatically.

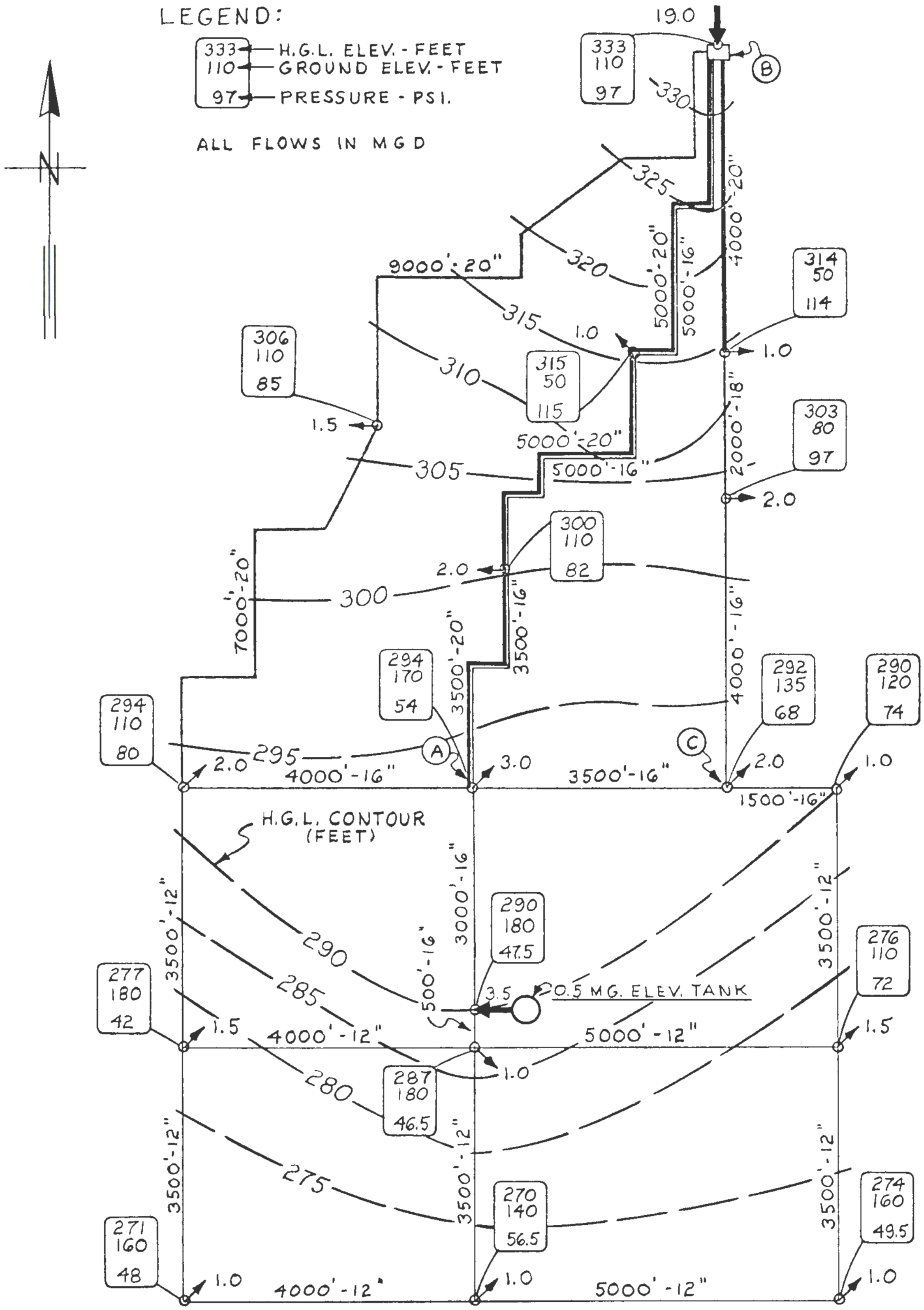

Figure 8. Distribution system analysis (additions to illustrative system)

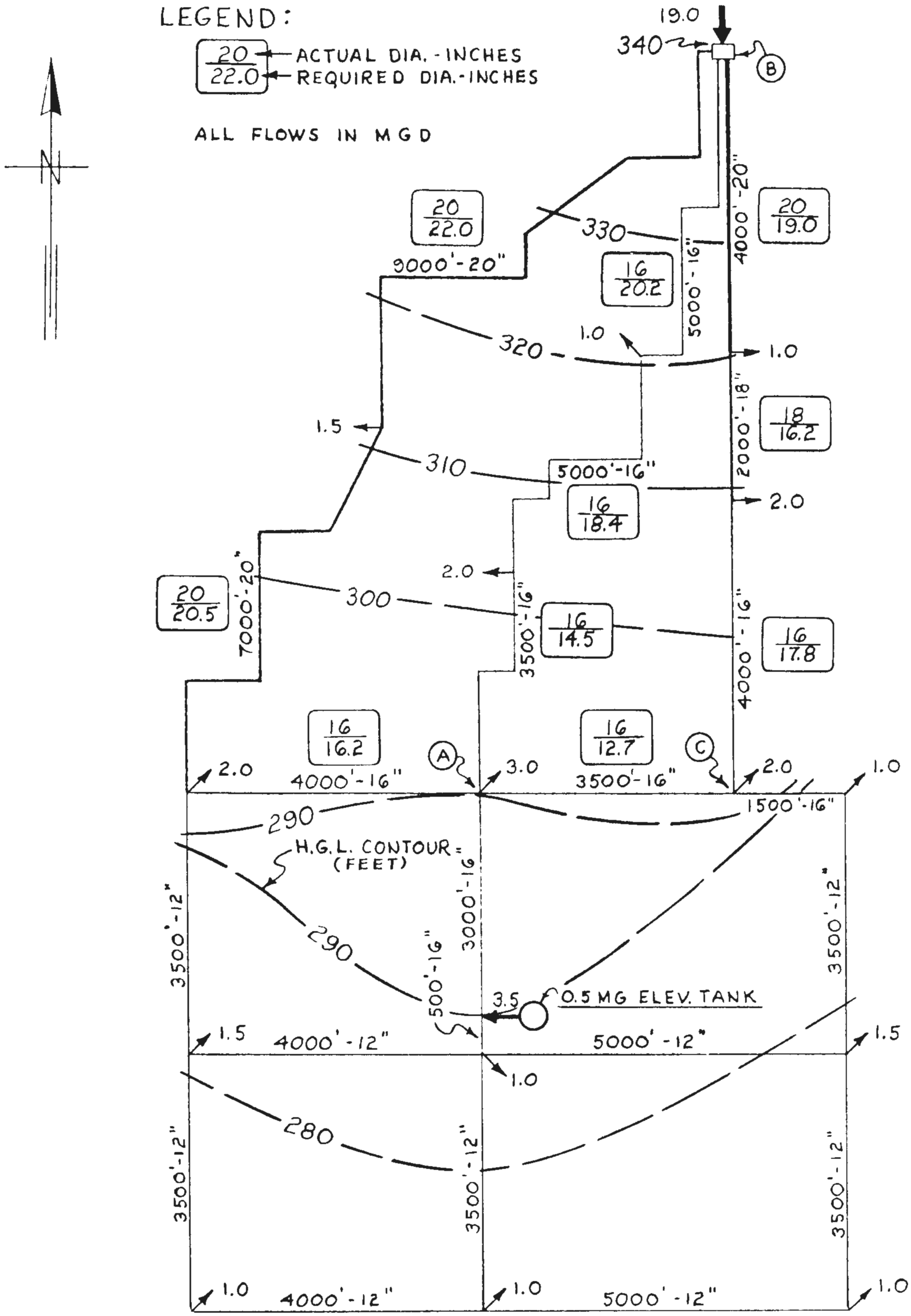

Figure 9. Distribution system analysis (additions by Tong method)

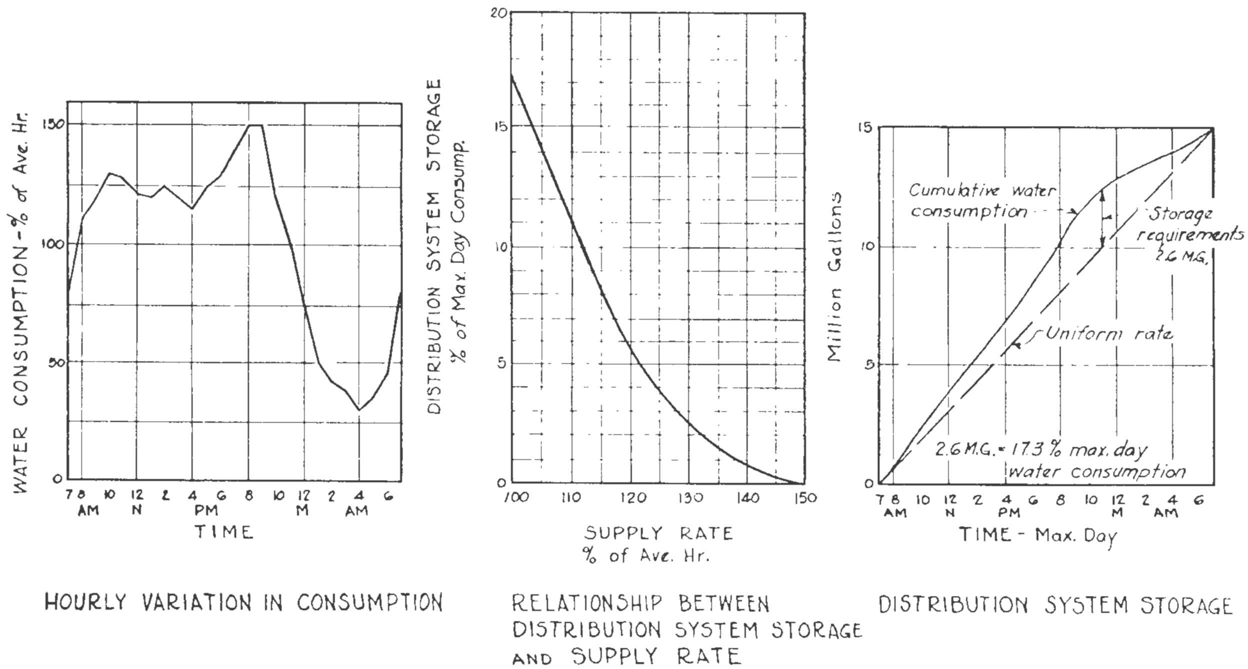

Figure 10. Distribution system storage

Storage

Storage may be provided for many purposes, but in its relation to distribution systems, two purposes appear dominant. These are as follows:

1. To supply for rates of water consumption in excess of the capacity of the supply works. This storage may be for either ordinary operating conditions or for fire protection.
2. To reduce the rate of water supplied from a single source and thereby affect pipe sizes in the distribution system, hydraulic gradients, or both.

Storage for either of these purposes may be at ground level or elevated.

The quantity of storage is related primarily to the capacity of the supply works, and to the use and location of storage in the distribution system. For example, if water treatment works are a part of the water system, it is economical to design the treatment works for the maximum day rate. All rates of water consumption in excess of maximum day rate therefore must be supplied from storage. For normal water consumption, the quantity of storage may be estimated from the hourly variation in water consumption. Storage for fire protection to sustain the fire flows for about ten hours are usually considered to be requirements in addition to normal operating requirements.

Storage for the requirements outlined above could be considered minimum requirements. Location on the system, zone operations, and special considerations may significantly increase the desirable quantity of storage.

DISTRIBUTION SYSTEM ANALYSES

Pipe network analysis, pumping station performance, storage and topography all become part of distribution system analysis. For the system shown on Figure 6, the maximum hour rate was 22.5 MGD, of which the rate of 3.5 MGD was supplied from the 0.5 MG elevated tank and 19.0 MGD was supplied from the pumping station. The maximum day rate is 15.0 MGD. The data on Figure 7 show that this rate could be supplied from the pumping station without additions to the pipe network. The hourly variation in water consumption, the relationship between pumping station capacity and distribution system storage, and the required distribution system storage if the pumping station rate is not to exceed the average hour rate on a maximum day are shown on Figure 10. This figure shows the total quantity of storage required on the distribution system to limit the pumping station rate to 15.0 MGD is 2.6 MG, of which 0.5 MG is already available. Thus, the problem of supple-

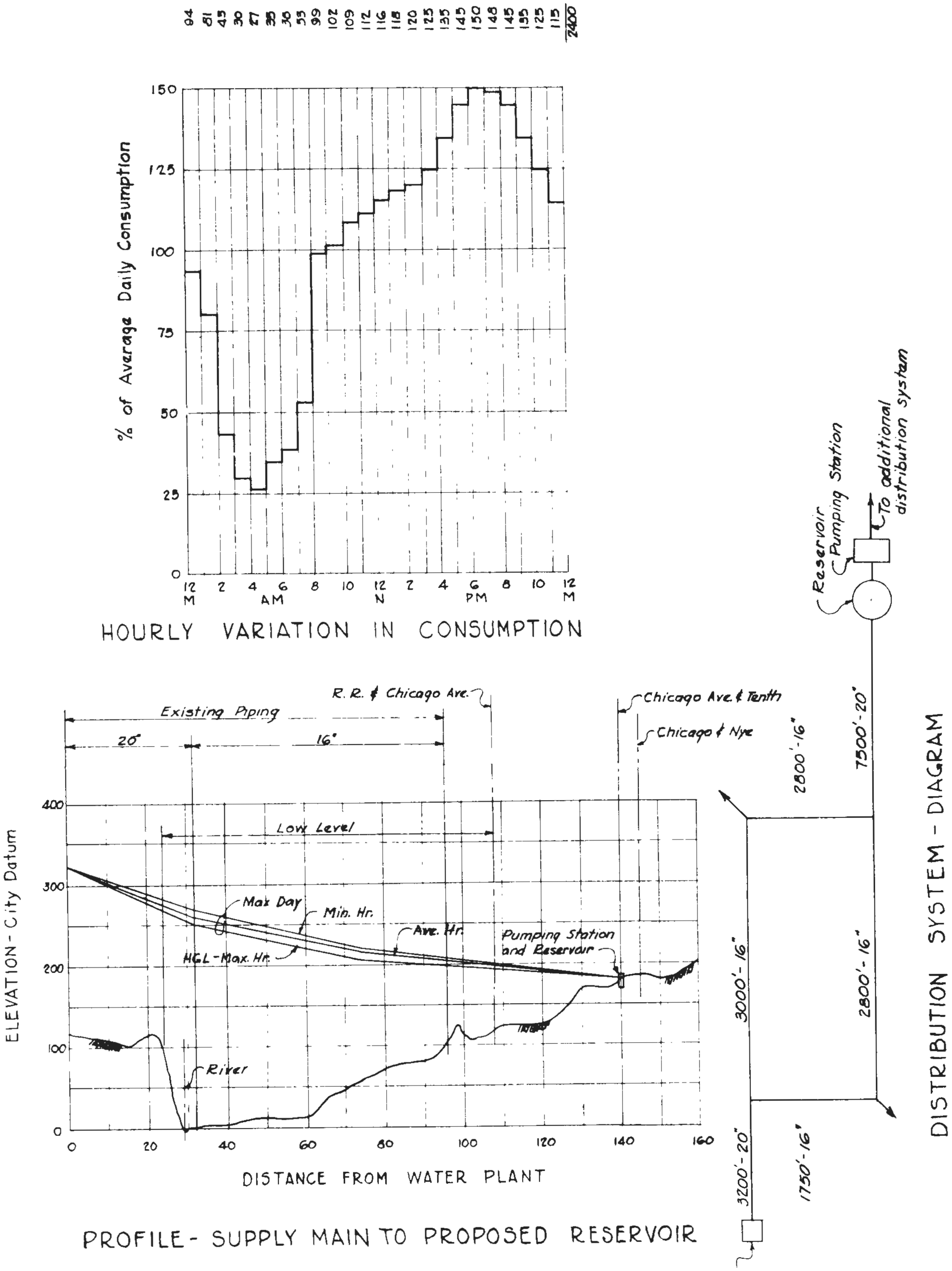

Figure 11. Plan and profile — zone system

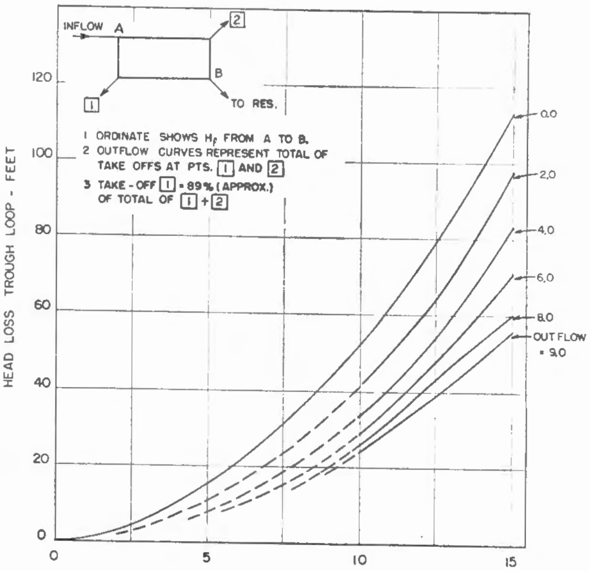

Figure 12. Head loss through loop varying water consumption

menting the distribution system shown on Figure 6 may be solved in at least three ways:

1. Provide an additional 20-inch main approximately 13,500 feet in length.
2. Provide about 2.1 MG of ground level storage with an appropriate pumping station in the vicinity of Point B, Figure 6.
3. Provide two 1.05 MG elevated tanks in the vicinity of Points A and C, Figure 6.

The choice can be determined largely by economics and by other needs in the system for fire storage, other operating storage, availability of land, and the like.

Topography can influence hydraulic design significantly. Figure 11 shows a diagrammatic plan, and profile of a portion of a distribution system and the hourly variation in consumption on a maximum day. The low area in the vicinity of the river experienced high pressures and the area on high ground remote from the pumping station frequently experienced low pressures. Water main construction to supplement the existing mains would be costly because of the river crossing and rock excavation, and while pressure in the high areas might be increased, the high pressure problems in the low area would be aggravated. The low area, however, may be treated as a low pressure zone and the water repumped to the high zone.

The method of computing the flow to the reservoir is illustrated as follows:

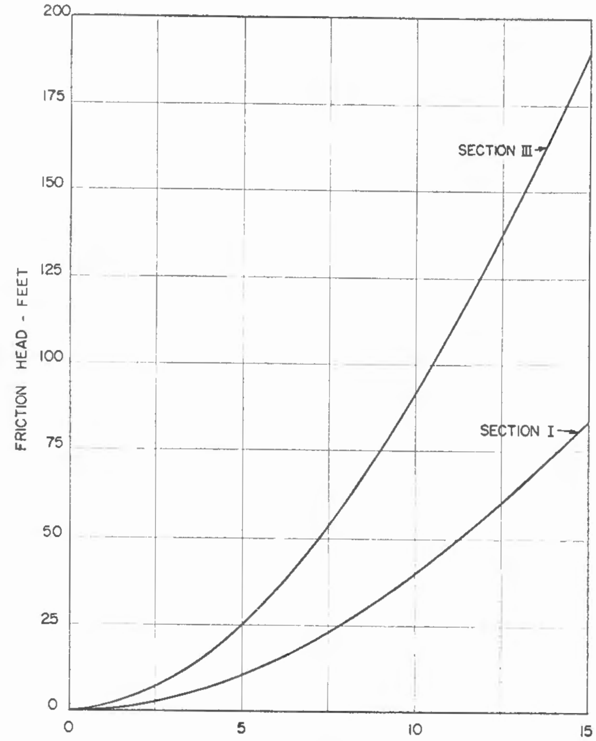

Figure 13. Head loss through pipe sections

1. The head loss through the loop portion for varying flow into the loop section and for various amounts of water consumption in the loop area is plotted on Figure 12.
2. The head loss through the sections without take-offs is plotted on Figure 13.
3. For a constant HGL at the water plant and a constant HGL at the reservoir, the total head loss between these points, regardless of water consumption, would be constant. The filling rate of the reservoir, however, would be variable. This filling rate is plotted on Figure 14.
4. The total water to the reservoir on a maximum day, shown on Figure 15, is 6.06 MG. The rate of pumpage from the reservoir is also shown on Figure 15. The minimum quantity of storage at this site is represented by the maximum ordinates between the inflow curve and the out-flow curves.

These illustrations are but two of apparently limitless variations on distribution system analyses. The fundamental hydraulics are applicable to all variations and the best and economical solution to

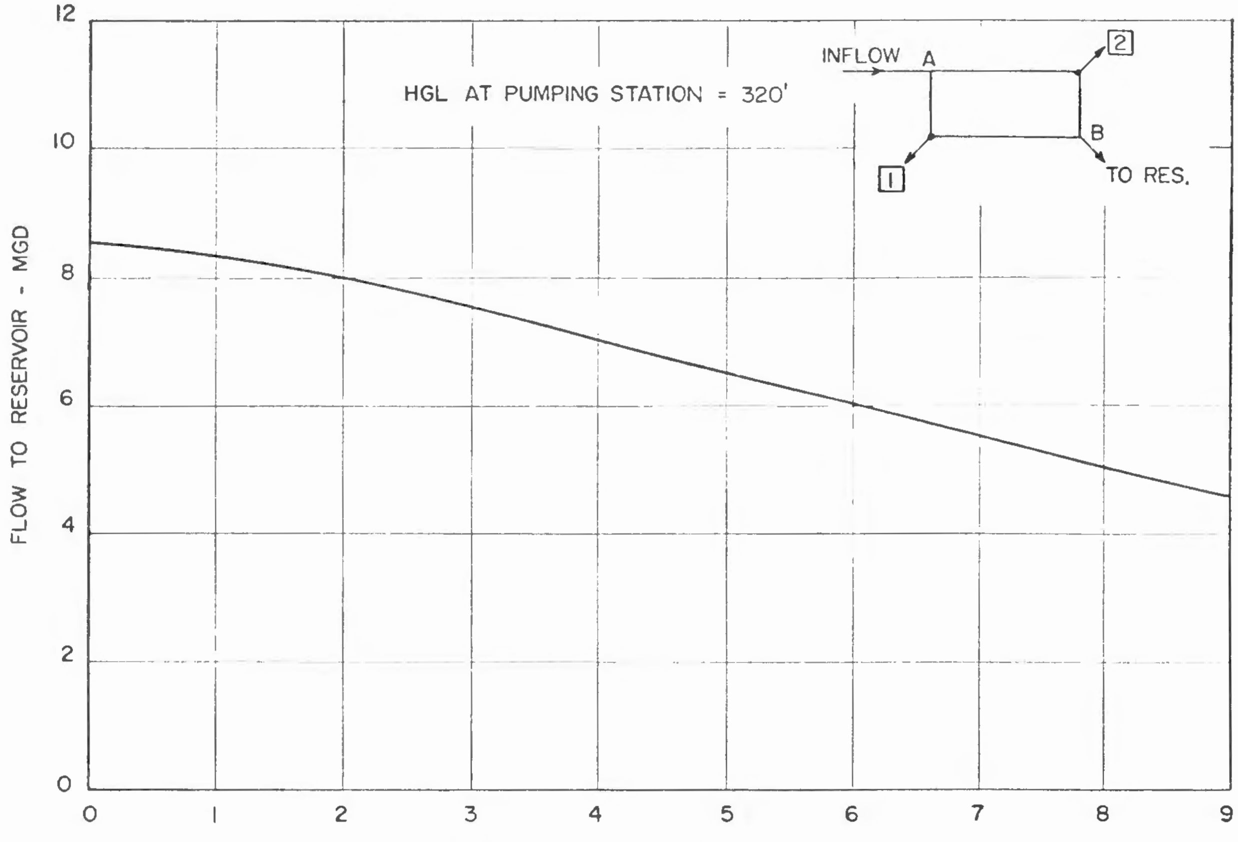

Figure 14. Flow to reservoir varying water consumption

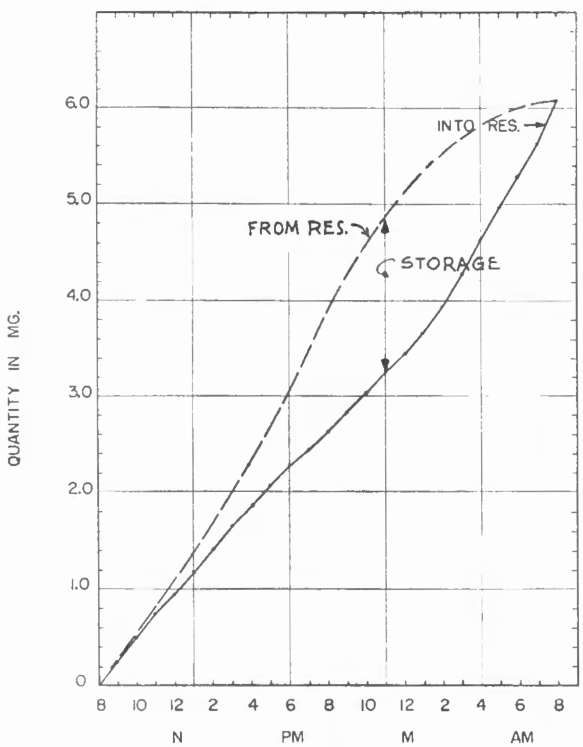

Figure 15. Cumulative flow to reservoir

any problem is a function largely of the imagination of the engineer.

MISCELLANEOUS

Two subjects which may warrant much consideration are Pumping Station Control and Surge Protection. Some brief thoughts on these subjects are therefore included in this paper.

Pumping Station Controls

Distribution system pumping stations may be controlled manually (either locally or remotely) or automatically. For automatic control, both pressure and flow may be sensed, but usually pressure only provides the control. Figure 16 shows the scheduled operation of a line booster pumping station arranged for automatic operation. It is important that the points for start and stop of each unit be well defined and arranged to avoid hunting.

Surge Protection

Serious water hammer may occur in distribution systems. Swing check valves do not provide a

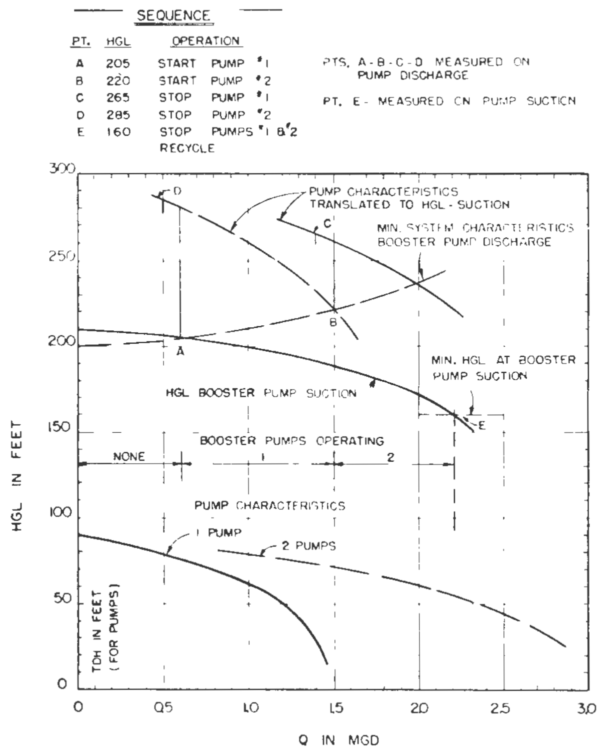

Figure 16. Booster pump operation — pressure controlled

means by which water hammer may be controlled. On all pumping units which may produce significant changes in velocity in the pipe system, some type of controlled closing check valve should be provided.

CONCLUSION

Systems for the analysis and design of distribution systems have been available for some time, but improved methods resulting from better understanding of fundamental hydraulic considerations are constantly being developed. Several papers presented in 1960 and 1961 attest to the study being given to this phase of water works practice. The use of computers has facilitated this study and wider use of computers is indicated.

As indicated in the Tong paper,[4] a program has been developed for balancing equivalent pipe lengths. McPherson[3] suggests that it is feasible to consider writing a design program for a digital computer which would permit direct determination of the best combination of pipes to satisfy prescribed conditions as defined by a generalized equation. It should be emphasized, however, that the use of computers can only supplement the imagination of the designer. Impossible solutions, such as a supply from an elevated tank when the HGL at the tank is below the tank bottom, will remain impossible whether the solution was achieved manually or with a computer. Adequate and economical distribution system design will remain largely a function of the competence and imagination of the designer.

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APPLICATIONS OF SYSTEM ANALYZERS: A SUMMARY

M. B. McPherson[1]

INTRODUCTION

The principal features, advantages, and liabilities of various devices used in calculating the hydraulic performance of water distribution system networks will be outlined. Because the reliability of results obtained via any computing device hinges greatly upon the accuracy and integrity of the input data, it is important that some of the more important engineering aspects bearing on technical decision-making also be reviewed. The concluding remarks will be concerned with the need for and potential value of more extensive and advanced techniques for system analyses than are currently being employed.

It has been stated succinctly that "All *instruments*, however elaborate and refined, are just tools along with hoes and hammers. They extend the power of our muscles, the length of our arms, and the sharpness and range of our perceptions. At the upper stages, culturally, come the tools which extend the powers of the intellect. And chief among these we count computing devices, or *computers*."[1] The abacus, the homely slide-rule and the desk calculator are thus rudimentary computers. In essence, all computing devices perform only the simplest operations, such as addition and multiplication, directly or indirectly, but the sophistication, complexity and versatility of calculation capacity depend upon the type of device used. The choice of a particular device is governed largely by the scope of service required. Will the device be utilized for a unique class or a broad spectrum of calculations? Justification for capital investment in any expensive device perforce requires an anticipated sustained and heavy usage. However, effective exploitation of a unique service feature may clearly justify selection of a specialized device for continuous or even occasional use. What, then, are the engineering applications at issue?

COMPUTER APPLICATIONS

Aside from data reduction, collation, and tabulation, the principal use of computers in water distribution design has been in the balancing of flows and head losses in distribution system networks. Because proposed operating revisions, proposed capital improvements, and anticipated future demands can seldom be simulated by manipulating the prototype network, recourse must be made to simulation by calculation. Assuming that adequate data are at hand, for a set of fixed inputs and demands, the equations representing the continuity of flows at each junction and head losses around each loop of the network must be solved simultaneously to achieve a *network balance*. The method of solution depends upon the type of device employed. While only recently recognized, detailed calculation of network-storage-pump balancing (*system balancing*) is of at least equal importance. However, the succeeding discussion will be directed towards network balancing applications. Consideration of system balancing will be deferred until later in the paper.

Every recognized authority predicts sustained increases in population, urban growth, and per capita demands for municipal water in the next several decades. The distribution systems of most water utilities represent the major share of total capital investment. Because many water mains are expected to survive a century of service, because the investment in them is so disproportionately large, and because their efficient performance may well determine whether a utility enjoys a profit or a loss, inefficient and time-consuming hand calculation of network balancing for engineering design must everywhere be replaced by more advanced and thorough methods, except in the instance of

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elementary networks for smaller hamlets and villages. What kinds of computers are available for network balance calculations?

COMPUTER TYPES

"The two major categories, nowadays, are called digital and analogical. The one deals in numbers only, the other in continuous physical variables. The first computes by repeatedly refining an approximation, and its accuracy (when consistent with input data accuracy) is potentially unlimited; in the second type some sort of physical model is set in operation to generate a solution which is valid by virtue of an analogy to the problem at hand. This latter type, the analog computer, is limited in accuracy by the physical elements of the model."[1]

The abacus and the desk calculator are digital computers, albeit elementary types compared with the electronic digital computer. A planimeter, slide-rule, nomograph, transit, and sextant would be regarded as analog computers.

Analogs are classified as *direct* or *indirect*. Indirect analog computors are utilized in the solution of algebraic and differential equations, both linear and nonlinear. Slide-rules and nomograms are mechanical indirect analog computers where the lengths on a stick or a graph are analagous to numbers. Analog devices used in network balancing are all direct. In a direct analog, problem variables and problem parameters are represented directly by variables and parameters on the machine. Analogs are further classified as passive or transient. A passive analog is a steady-state, or constant flow, device. Analog devices used in network balancing are either passive or are transient analogs operated as passive machines.

A direct analog, although not usually called a "computer," is a scaled model wherein the network to be balanced is replaced by a miniature liquid system with general physical features resembling the prototype. Attempts have been made to simulate the hydraulic characteristics of elementary network water mains using pinchcocks,[2] short capillary tubes within larger tubing,[3] small orifices[4] and glass tubing.[5] Seldom can more than a qualitative estimation of flow and head loss be obtained from models. This is compounded by the fact that model flow is usually in laminar (wholly viscous) state whereas prototype mains of design significance almost exclusively flow in turbulent state.

Direct analogs utilized for distribution network balancing include electric service power-system calculating boards and the McIlroy Fluid Network Analyzer. Both analogs are often called "analyzers."

ELECTRIC SERVICE POWER-SYSTEM CALCULATING BOARDS

A D.C. power network analyzer was the first of this form to appear, in 1925. Because this type is purely a resistive analog, it is limited to passive, or steady-state, problems. Introduction of A.C. power network analyzers in 1929 made possible the simulation of alternating current power networks in terms of phase and magnitude. The resistances in D.C. power analyzers and the resistances and impedances in older A.C. power analyzers are linear in characteristic. That is, the voltage drop across an element is proportional to the current to the first power. In more recent times a transient power network analyzer has been developed by the General Electric Company in which nonlinear elements can be simulated.

The flow of water in pipes at turbulent state follows a nonlinear resistance relation, with head loss a function of the flow to a power varying between 1.75 and 2.00.

Camp and Hazen[6] were probably the first to adapt linear resistance D.C. electric power computing boards to the balancing of water distribution networks. Camp[3] reported somewhat later on a similar adaptation of A.C. linear resistance computing boards. The voltage drop E across a linear resistance, R, is

$$E = RI \tag{1}$$

where I is the (direct) current. The expression for the head loss (analogous to potential drop) in a water main may be reduced to

$$h = kQ^{m} \tag{2}$$

where k is a resistive term embodying length, diameter, and friction coefficient, Q is the rate of flow (analogous to current) and m is a power varying between 1.75 and 2.00 for turbulent flow. To obtain an analogy, Equation 2 can be rewritten in the form of Equation 1 by

$$h = (kQ^{m-1})|Q| = k_0|Q| \tag{3}$$

where k_0 represents a particular pipe linear resistance which happens to be equivalent to kQ^{m-1}. For the Williams-Hazen equation, $m = 1.85$, or

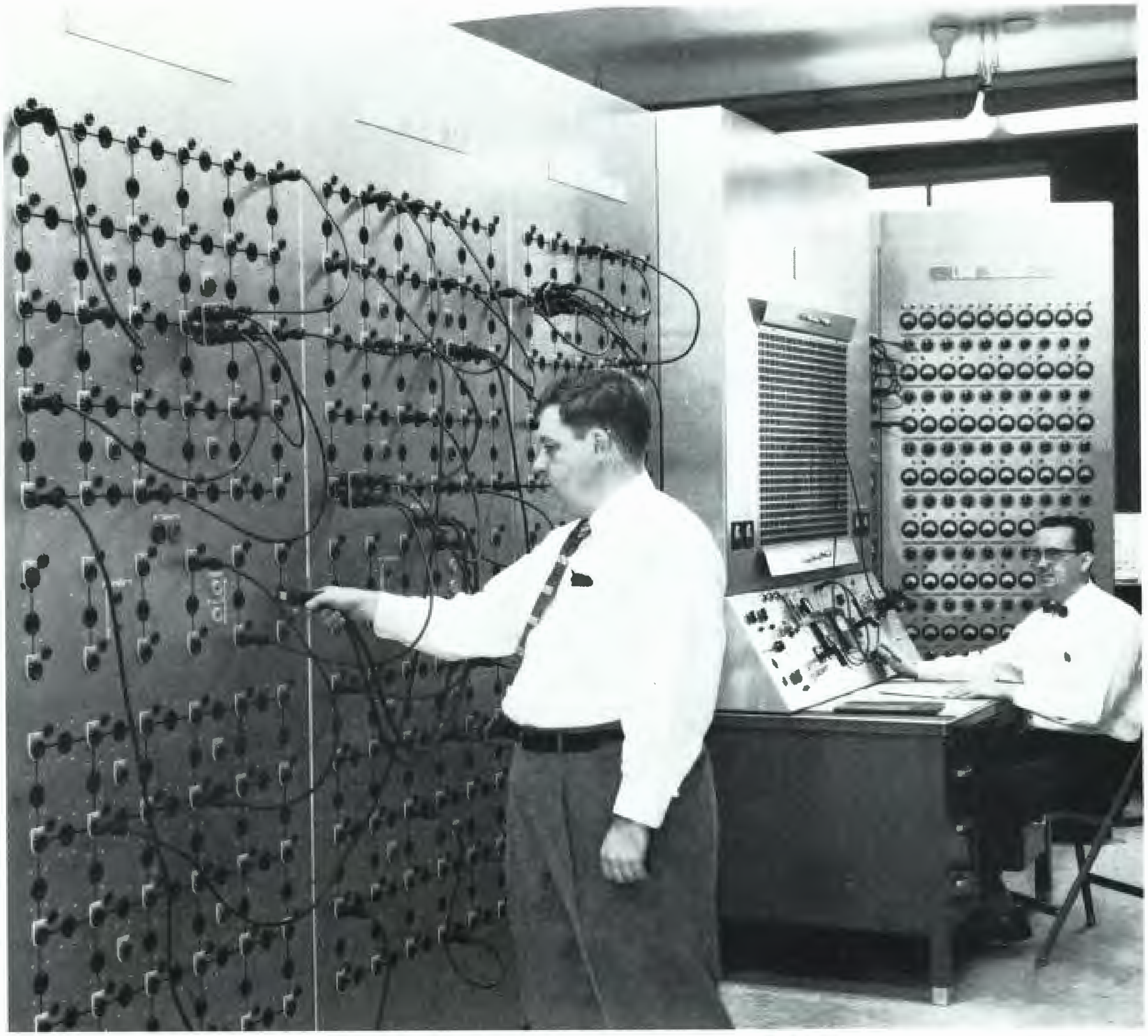

Figure 1. Philadelphia Water Department McIlroy Analyzer (front view)

$$h = kQ^{1.85} = (kQ^{0.85})\ |Q| = k_0|Q| \qquad (4)$$

By successive adjustment of the linear electrical resistance values R analagous to k_0, a final set of k_0 values can be obtained which satisfy Equation 3 in the instance of each and every "pipe." The adjustments comprise successive changes in the settings of ordinary linear resistors in the direction indicated by the preceding trial. Algebraic sums of currents at junctions and voltage drops around loops are automatically zero because the linear resistance electrical network is always in balance. However, for each pipe only one $|Q|$ and only one associated value of k_0 will satisfy simultaneously the prescribed k in kQ^{m-1}.

The general features of A.C. calculating boards have been given by Reid and Wolfenson.[7] Valuable techniques have been offered to speed convergence.[8, 9] Clennon[10] has described gas network applications. Availability of power-system analyzer staffs with experience in balancing water distribution networks is not extensive, but some services are available on a rental basis.[11]

McILROY FLUID NETWORK ANALYZERS

The outstanding feature of the McIlroy Analyzer is a system of nonlinear resistances, called *Fluistors*. Each Fluistor consists of a tungsten fila-

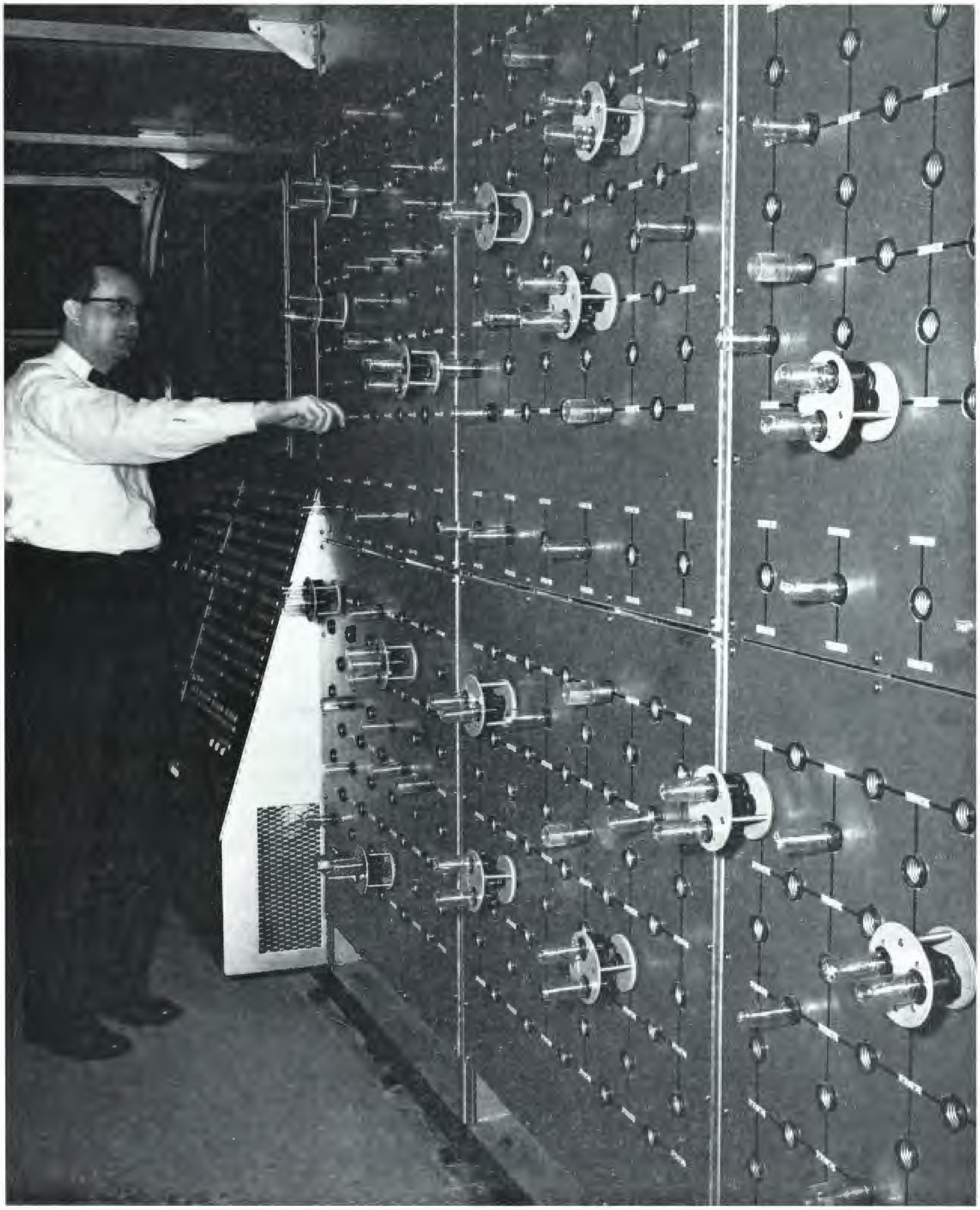

Figure 2. Philadelphia Water Department McIlroy Analyzer (rear view)

Table 1

McIlroy Fluid Network Analyzers in Operation (1961)*

Cornell University	Consulting
Washington State University	"
University of Kansas City (formerly at Midwest Research Institute)	"
Laclede Gas Company	Gas Utility
Columbia Gas System, Inc.	"
Public Service Electric & Gas	"
U. S. Bureau of Mines	Mine Ventilation
City of Baltimore	Water
City of Philadelphia	"
Southern California Gas Co.	Gas Utility
Baltimore Gas & Electric Co.	"
Philadelphia Electric Co.	"
Washington Suburban Sanitary Commission	Water
Tufts University	17 Mass. Gas Utilities & Consulting
Philadelphia Gas Works	Gas Utility
Baltimore County	Water
Citizens Gas & Coke Utility	Gas Utility
Western New England College	Consulting

* (Courtesy, The Standard Electric Time Co., Springfield, Mass.)

ment mounted in an evacuated glass bulb. For a Fluistor, with a direct current

$$E = RI^m \tag{5}$$

By proper selection and use of Fluistors, any value of m between 1.85 and 2.00 can be closely approximated. Because Equation 5 is completely analogous with Equation 2, a D.C. network simulating the features of a given hydraulic network can be interconnected and energized, and measured voltages and currents can be read directly on special multiplier meter scales in units of head loss and flow rate.

Considerable information on details and operating features of the McIlroy Analyzer with regard to water service have been presented.[12-16] Each machine is tailored to customer specifications. In Figures 1 and 2 are shown front and back views of the Philadelphia Water Department's Analyzer installed late in 1955. Note the Fluistors connected to the rear panel in Figure 2. This particular machine is of medium size and its cost would compare rather closely with that of one of the smaller digital computers.

Figure 3. Western New England College McIlroy Analyzer

Figure 4. Console of the Western New England College McIlroy Analyzer

The eighteen existing McIlroy units are identified in Table 1. It may be noted in Table 1 that McIlroy Analyzers are also employed in mine ventilation[17] and gas[18] network balancing. The Philadelphia Electric Company machine is also used for balancing of steam networks. Only four machines are owned by water utilities against eight by gas utilities. Five machines, all owned by colleges or universities, are available on a rental basis to consulting firms and utilities (one had been used at a research institute).[19] Details on the services available for three of the machines have been reported.[20, 22]

For the first seventeen machines listed in Table 1 it is necessary to connect ammeter and voltmeter leads into receptacles on the network panels for head loss and flow measurement. In Figure 1 note that the network panels are somewhat removed from the control console, which precludes efficient operation of the machine by only one person. In the latest version of the analyzer, the unit at Western New England College in Springfield, Massachusetts, head losses and flows may be read directly from the instruments at the control console without connecting meter leads to the network panel (Figures 3 to 5). Pushbuttons at the console permit selection of any point in the network for measurement, which accelerates data readout and recording, and makes possible efficient operation by only one man. A fee of $300 per day, including services of an operator, is charged for use of this analyzer on a consulting basis.[22] This machine has a total capacity of 12 inputs or sources, 447 pipe sections, and 180 outputs or loads. For general comparison, the analyzer in Figures 1 and 2 has a total capacity of 11 inputs or sources, 312 pipe sections, and 73

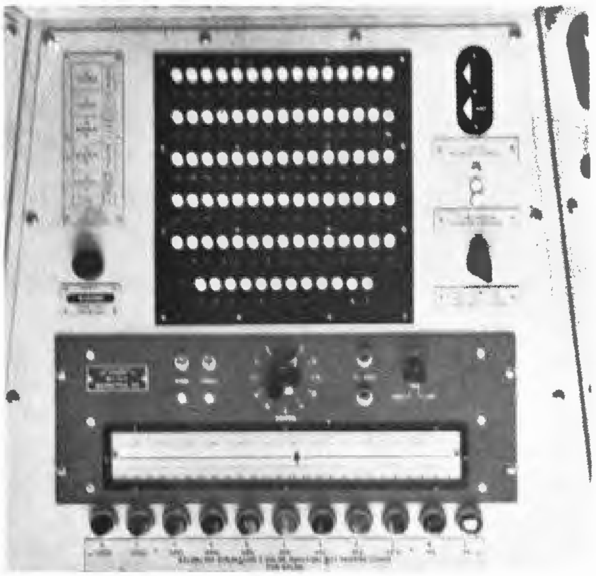

Figure 5. Pushbutton panel of the Western New England College McIlroy Analyzer

outputs or loads.[15] "The analyzer at Tufts University can represent up to 500 pipes, 225 loads, and 36 sources."[23]

Discussion of advantages which accrue with effective exploitation of McIlroy Analyzers will be deferred until digital computer applications are reviewed.

DIGITAL COMPUTERS

The first large-scale general purpose digital computer was installed at Harvard University in 1944. There are now scores of large machines and myriad medium and small general purpose machines in the United States. When digital computers became commercially available on a large scale the iterative (a succession of trials) convergence technique for balancing water distribution flows and head losses originated by Hardy Cross in 1936[24] truly came of age. Effective exploitation of the Cross technique in hand balancing calculations has been limited to simple networks (by today's standards) because the work involved is extremely time-consuming, tedious, and monotonous.

In the Cross technique, the "correction" to be applied to the flow in each pipe of a given loop for each iteration, or trial, is:

$$\Delta = \frac{\Sigma k Q^m}{m \Sigma k Q^{m-1}} \qquad (6)$$

One commences with a set of assumed pipe flows which satisfy only the condition that the algebraic sum of flows at each and every junction are zero. A flow correction is calculated for each loop via Equation 6. Because a given pipe usually is a branch for more than one loop, the algebraic sum of adjacent loop Δ's must next be used to modify the initially assumed flow for each pipe. A second, third, etc., set of corrections are calculated and applied, until an acceptable degree of balance is achieved throughout. The modification of an input relation by some fraction of the corresponding output relation is termed feedback. The Cross technique thus applies a feedback process to an orderly sequence of calculations. The electronic digital computer is ideally suited to sequential calculations with feedback.

The illuminating gas industry appears to have preceded water utilities in the adaptation of the Cross technique to network balancing using digital computers. Six of the monthly issues of *Gas* in 1955 (particularly January, May, and September) outlined a series of symposia on the use of various types and models of computers.

In 1957, Hoag and Weinberg[25] presented a skeletonized programming flow chart for balancing water distribution networks via the Cross technique. A few months later a similar flow chart was published.[26] In 1958 Graves and Branscome[27] presented a detailed flow chart and program. In a discussion, Hamblen[27] outlined a modification of their program better suited to larger networks. In each instance an IBM 650 was employed.

Starting with assumed balanced junction flows, the limit of acceptable convergence can be dictated in terms of a maximum loop head loss imbalance[25] or a maximum allowable loop flow correction Δ[27] for any loop in the network. The former is more meaningful. In general, only interior, individual loops are tested; and overall exterior or compound loops are not subjected to the test criteria. "The number of iterations required has been found to be not a function of the original assumption but of the complexity of the system."[26] However, the limit of acceptable imbalance and the inclusion or omission of modifications to accelerate convergence[25] have a bearing on the number of iterations for a given network.

The following data will give some idea of the number of iterations required:

Number of Loops	Iterations	Identification	Reference
5	13	Fort Worth, Texas	(26)
5	3	Dallas, Texas	(20)
10	12	Delaware	(26)
13	16	Dallas, Texas	(26)
22	8	Crescent City, California	(26)
38	37 (unmodified)	Palo Alto, California	(25)
38	21 (modified)	Palo Alto, California	(25)

"A total of eight different solutions (balances) was performed for the Palo Alto system, requiring about 2¾ hr of machine time and involving a cost of perhaps $500 including keypunching, machine rental, and engineer's tabulation and checking time." Network balances were obtainable from a service center by correspondence:[28] the charge (1957) was 42 cents "per loop per iteration required to achieve a stated head loss accuracy"; the maximum number of loops which could be accommodated is 50.* Digital computer service for network balancing is available from at least one university.[21]

Cross[24] also considered a variation in his convergence technique which commences with an equilibrium of loop head losses rather than junction flows. Iteration proceeds in the same manner until the sum of flows at all junctions is within a prescribed tolerance. Cross indicated that this variation would be superior for some network configurations. Convergence could be directed towards a maximum allowable loop flow correction Δ or a maximum allowable junction flow imbalance. The writer has been informed that the modified approach has been programmed recently for a computer by a gas utility, but he is unaware of any water distribution applications.

A convergence technique completely different from the Cross method was developed by Warga[29] in 1954. The development of the method is in terms of *Procedure I,* "apparently new," and *Procedure II,* based on the Newton-Raphson method for iterative convergence. The procedures "permit an extremely simple program for digital computers, with the minimum use of memory space." "This code can easily be modified to permit, with use of magnetic tape, the handling of networks with several hundred loops and more complicated functions of (flow). A few sample problems involving gas flow were solved using this code." Warga demonstrates that his procedures converge, and on a unique solution, under boundary conditions which can be satisfied rather easily in most instances. He cautions that no evidence exists which proves the Cross method converges either in general or under special conditions, and that for both his and the Cross method "examples can be given where both fail to converge and oscillate indefinitely between two sets of values." The writer knows of an instance wherein a large gas network would not balance using the Cross technique and "hunting" of this sort took place. While satisfactory balancing is normally achieved, mathematical combinations inadvertently might be used which would preclude convergence.

* For details on a currently available service see Royal McBee under Digital Computer Users' Library Programs in this paper.

COMPARISON BETWEEN DIFFERENT DEVICES

The merits of the different types of computers used in network balancing were reviewed in 1958[30]:

The McIlroy Analyzer provides a direct, working analog of the system under study. "In operating the analyzer, drawoffs are set at prescribed *full* load values, and system inflow rates (from pumps or storage) are brought up from zero to system capacity. Often, in design analyses, needed system revisions are evident at inflow rates well below the design rates; obviously needed piping improvements are then made prior to any formal or complete test runs. Trial changes can be made in a matter of minutes. For example, changing the distribution of inflow between two pumping stations can be accomplished by adjusting two or three dials. The most valuable attribute of the McIlroy Analyzer in this respect is the elimination of unrealistic or superfluous or discordant arrangements with quick, simple, direct dispatch."

The electronic digital computer adjusts flow rates, initially assumed by the engineer for each pipe branch, to any degree of desired balance in an iteration process guided by a convergence technique. Computer output is normally presented as tabulated head loss and flow rate (with direction) for each pipe branch, and these must be transferred to a network map and summed algebraically before the significance of the results can be appraised. Any modification of loads or hydraulic characteristics desired for a subsequent balance requires appropriate changes in the data input. Punch card inputs are particularly convenient where few data input changes are required because new cards can be substituted immediately after they are punched. Editing magnetic or punched tape can be troublesome unless confusion is precluded by suitable format. An error in programming or data input generally is not evident until the output is completely summated and checked. Because of the many numerical values which must be processed, "the possibility of errors in data instructions is evident, particularly with medium to large networks. Further, the 'model' visualization feature of the McIlroy Analyzer is completely absent from the digital computer."

By means of a series of trial runs with intermediate computations and rheostat adjustments, network balancing can be performed by using electric service power-system calculating boards with linear resistors. The calculating board is similar to a digital computer to the extent that the final result is all that is obtained; it lacks most of the working analog features of the McIlroy Analyzer.

The cost of the medium size McIlroy Analyzer illustrated in Figures 1 and 2 is about the same as for a small desk-size digital computer. This analog device is a single-use machine, designed specifically for fluid network balancing. On the other hand, a small digital computer can be employed in the solution of a multitude of different problems. Purchase of a McIlroy Analyzer can usually be justified only when a sustained use is expected. Although the analyzer in Figures 1 and 2 is used an average of only one or two full days each week, its cost was offset in the first months it was used by savings afforded in more closely controlled design of capital improvements.

The analog features of the McIlroy Analyzer are outstanding where distribution design is a vital or full-time occupation. The design engineer gets the "feel" of the whole system as the required demand is approached. System revisions can be made in a matter of minutes. Decisions concerning revisions or alternate schemes can be made most effectively by immediate appraisal of the results as modified or evaluated in terms of observed, mentally recorded trends. Proportionate head loss in mains is indicated by the comparative brightness of the resistors. Thus the resistors and flow and head meters provide a special auxiliary service as instantaneous, simple visual aids.

"With the digital computer, on the other hand, the designer gets only a tabulated summary which is meaningless until analyzed in toto. The elapsed time between conversion of the problem into simple arithmetic and interpretation of the final results contributes nothing to the problem evaluation. Possible revisions or alternate schemes are not readily suggested. Physical identity with the problem is lost and the solution is reduced to abstract numbers in tabular form."

For the consulting or utilities engineer to whom network balancing is only an occasional problem the preferred design tool would still be a McIlroy Analyzer. *However, the analog device has no advantage over a digital computer or calculating board if the design engineer is not present to make design decisions as the analyses proceed.* Because of the waiting time between balances, occasioned by necessary changes in input and probable competition for machine time for other purposes, and because nothing other than the final balance is obtained, there is no technical advantage in the design engineer being present while a digital computer masticates numbers. This applies to calculating boards as well. There are three basic choices: (1) rent time on a McIlroy Analyzer and be present while it is operated; (2) have balances run on a digital computer or calculating board by correspondence; (3) prepare or have a program prepared or obtain a program from the User's Library for the firm's digital computer, or for a computer owned by a nearby computing service organization.

Cornell[31] reported on comparative estimated costs for balancing a 30-loop network with a total input of about 22 MGD by hand, by digital computer, and by McIlroy Analyzer:

		Succeeding Balances	
Method	*Total Cost, First Balance*	*Number*	*Cost per Balance*
Hand	$ 59.50	1	$42.50
Computer	75.62	3	49.17
McIlroy	154.00	8	14.73

To the costs for the McIlroy would have to be added travel and subsistence if the machine were located some distance away. "The cost for additional analyses by the analog does not reflect the many partial analyses and quick checks of changed pipe size or flow that were performed in a matter of minutes and discarded without complete tabulation."

Cornell states in his conclusion: "With the es-

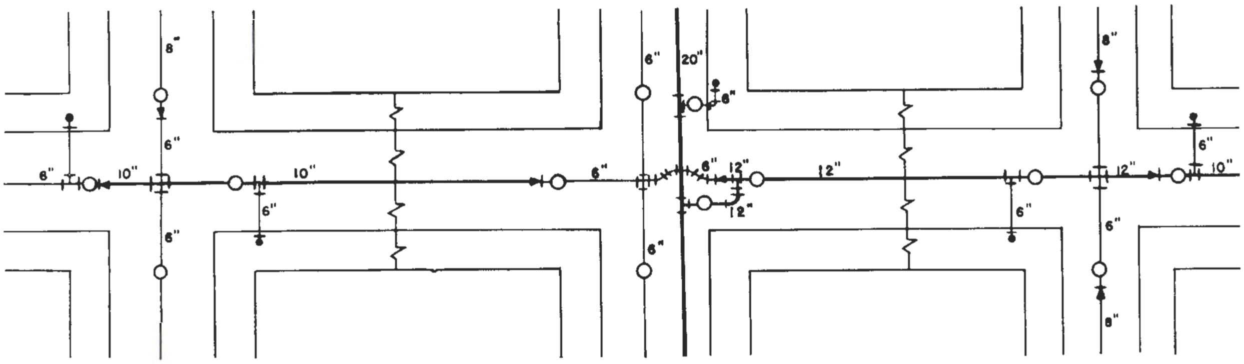

Figure 6. Grid main and connection to arterial main, Belmont High Service District

tablishment of computer centers throughout the country, and with adequate programs for network analysis (balancing) now developed, even the small system or the smallest design office can make use of computer analysis if it so desires."

ENGINEERING ASPECTS OF NETWORK BALANCING

The basic objective of network balancing is generally the determination of head losses; and the distribution of flows is a necessary by-product but a secondary consideration. The sizing of mains is usually governed by the largest head losses associated with peak domestic or fire flow demands anticipated under *future* conditions. Whether a domestic or a fire flow peak is critical depends upon the size and character of the service area and the hydraulic characteristics of the network.

Distribution piping must be designed consistent with its expected life of service, which may be as much as a century or even possibly longer. To reiterate an earlier statement, every recognized authority in the land predicts sustained increases in population, urban growth, and per capita demands for municipal water in the next several decades. Head losses for peak demands under existing conditions can often be estimated by means of extrapolated, direct field tests. Investigations of future conditions almost invariably are involved in enlargement of existing facilities to meet larger demands. The fidelity of an engineering design depends upon the astuteness of the designer and the degree to which future conditions coincide with his prophesies. No design of a distribution system should be regarded as fixed or permanent. It must be reviewed and modified to conform with future actualities as they occur or are more closely approached, in systematic, periodic reappraisals and revaluations. Flexibility should be a basic feature in all designs so that modifications in strategy can be effected with a minimum of restraint. The distribution supervisor should operate the system and not the other way around.

"Until much more elaborate computer programs than those currently available are developed, the hard work of reaching a decision on the basis of incomplete, questionable, and often conflicting information must still be performed by a human being. There is a tendency, as is often the case with elaborate systems of analysis, to place great faith in the results of a network analysis (balance) simply because they are obtained by an erudite method or a complicated machine. Such an attitude is dangerous. No analysis is more dependable than the assumptions and data on which it is based. The computer, regardless of type, is not yet capable of examining the pipe and deducing a proper coefficient of friction, or of guessing what the future demand may be. Thus all analyses must be viewed only as tools that the operator or designer uses to assist his judgment on the needs of a system."(31) Appreciation of these limitations might be deepened by a review of some of the major objectives, assumptions, and expedients in network balancing.(32)

NETWORK LOADING

The hydraulic characteristics of a distribution system are generally assayed by "skeletonizing" or reducing the system to an arterial network. The grid main in Figure 6 constitutes one of the three arterial connections of the surrounding grid sector, Figure 7. The grid sector in Figure 7 and grid main of Figure 6 are identified in the district arterial network plan, Figure 8. Returning to Figure 7, the

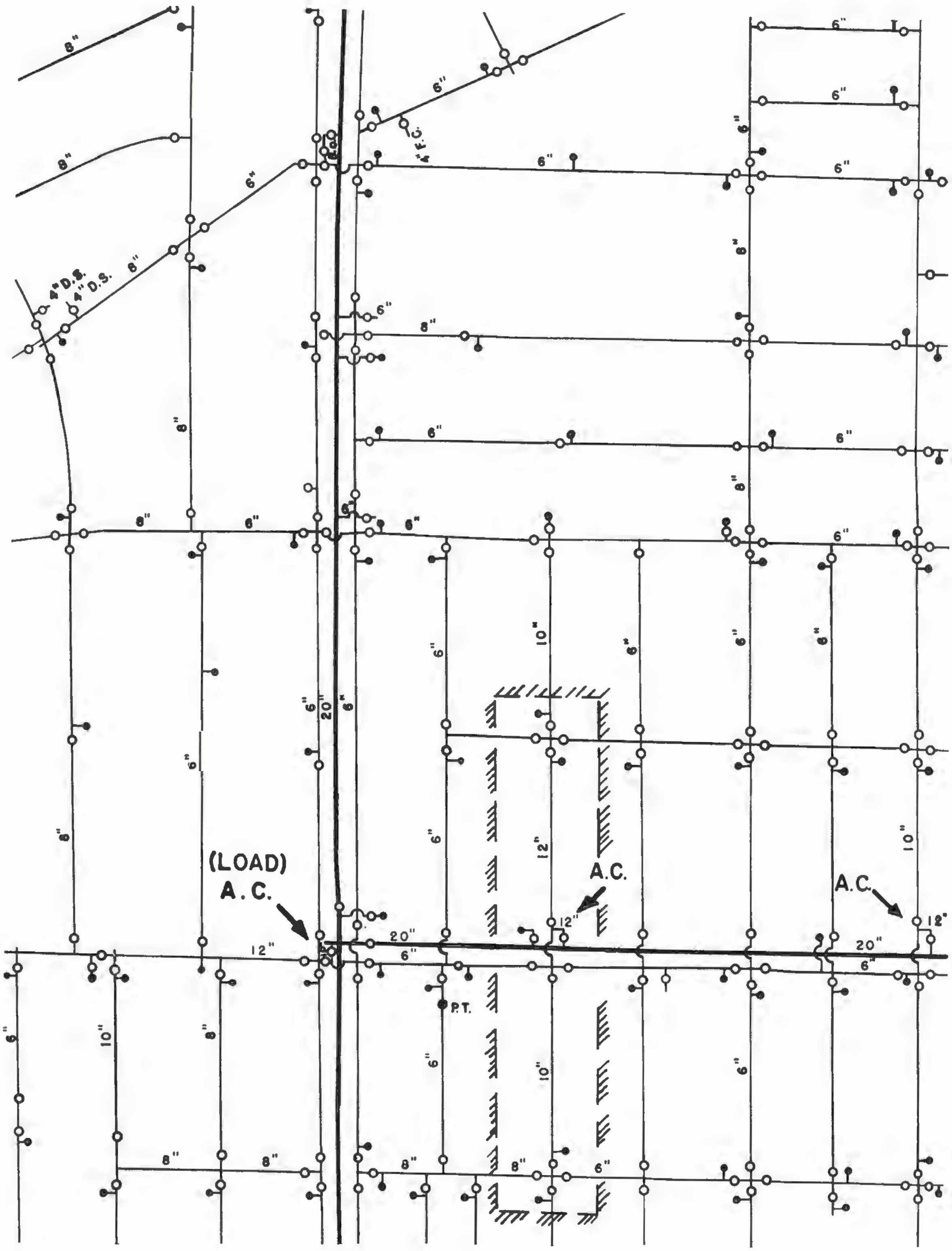

Figure 7. Intermediate grid sector, Belmont High Service District

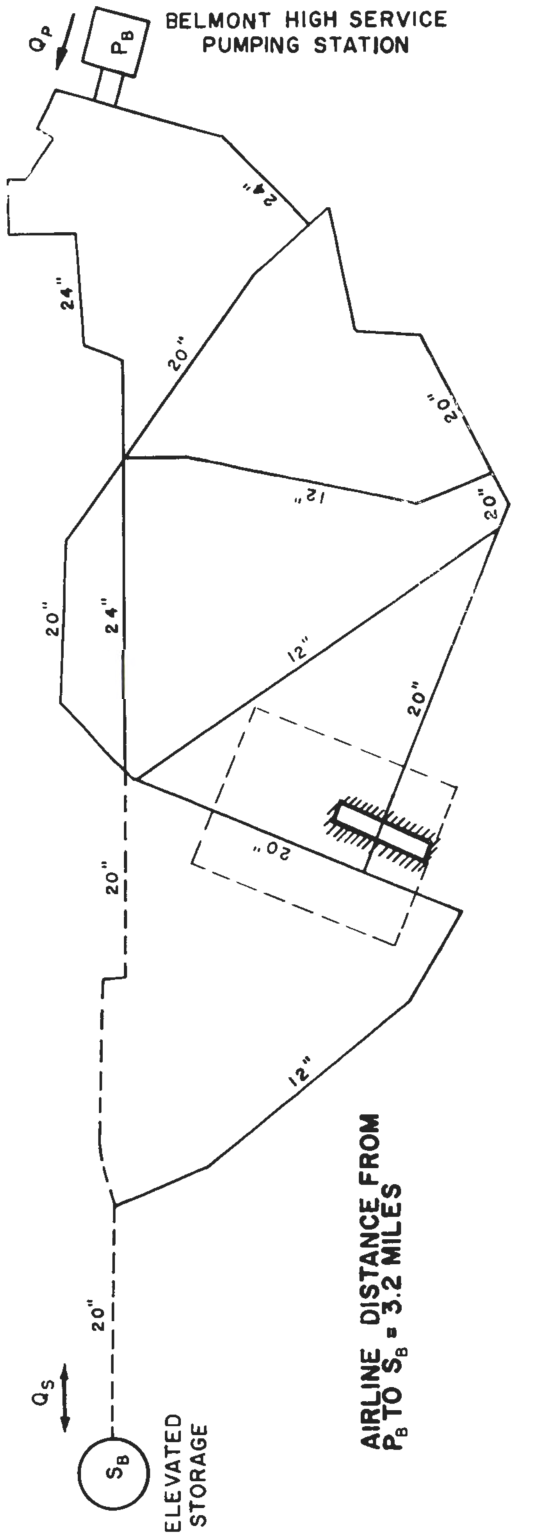

Figure 8. Belmont High Service District arterial piping network

three arterial connections shown were consolidated for study purposes at the single point marked "Load." In Figure 8, the 44 grid-to-arterial connections, on the 20-inch and 24-inch arterial mains shown as solid lines, were consolidated into 14 arterial loads for study purposes. A number of grid-to-arterial connections on the 12-inch and dashed line ("proposed") 20-inch main were consolidated into six arterial loads, for a grand total of 20. Consolidation of loads is undertaken not merely for simplification but because further elaboration would not be consistent with the load data used. The demand assigned each load is usually proportioned in accord with its probable share of the total district's average annual demand because the most reliable information, meter readings and leak-and-waste survey data, is usually in terms of an average demand rate. Further, because adequate supporting information is seldom available, it is commonly assumed that the fluctuation of each load has been and will be proportional to the total district demand.

GENERAL RESISTANCE DIAGRAM

Realistic design of any network requires a good knowledge of existing pipe friction coefficients. However, even in the most painstaking survey, neither all the arterial mains in a system nor all segments of the pipes calibrated are accessible for field loss measurement. Field head loss measurements over a range of significantly different rates of flow can seldom be justified because of attendant high costs, and measured friction coefficients have to be extrapolated for higher flow rates, particularly those for future peak conditions.

As a part of the classical work of Prandtl, von Karman and Nikuradse on turbulent flow pipe friction, it has been demonstrated that friction factors for the hydraulically smooth regime are a function of Reynolds number and for the hydraulically rough regime are a function of relative roughness. The transition regime between the hydraulically smooth and hydraulically rough regimes for new-condition commercial-type pipe roughness was approximated by Colebrook and White. The equation they developed empirically was incorporated into a general resistance diagram for pipes, first by Rouse[33] and then by Moody.[34] It seems that because the pub-

Table 2

Departure of Williams-Hazen f from Moody Diagram f

Diam.	C_o	With equal values of f at h_f/L = 0.2-ft./1000-ft., differences at h_f/L = 2-ft./1000-ft. are: $\frac{f_{WH} - f_m}{f_m} \times 100$	$\frac{(e/D)_{WH} - (e/D)_m}{(e/D)_m} \times 100$
12-in.	80	−17%	−35%
	100	−16%	−41%
	120	−13%	−44%
	140	− 7%	− 6%
	148	+ 2%	0%
48-in.	80	−18%	−40%
	100	−16%	−49%
	120	−16%	−50%
	140	−10%	−53%
	155	+ 1%	0%

Note: Because h_f is proportional to f, the third column percentages apply also to corresponding values of h_f. The h_f via Moody Diagram for −18% is therefore 2.41-ft./1000 and for +2% is 1.96-ft./1000-ft.

lication in which Moody's paper appeared was much more widely circulated, the technical public are predisposed to call the described general resistance diagram for commercial pipes the "Moody Diagram."

Well before the time the foundations of the general resistance diagram were being laid, Williams and Hazen[35] developed an empirical equation of fit to selected data. It is now accepted that in the hydraulically smooth regime at low Reynolds numbers head loss varies as the 1.75 power (m in Equation 2 of velocity or discharge, and that for hydraulically rough pipes head loss varies as the square. The Williams-Hazen equation gives a value of m = 1.85, implying that most of the data used in the curve fit were for conditions between the two extremes, for the transition regime. The general resistance diagram is expressed in terms of a friction factor, f, in

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \tag{7}$$

where h_f is the head loss in feet for a diameter D, in feet, of length L, in feet, at a mean velocity V in feet per second. The friction factor (f) has no dimensions and for turbulent flow is a function of relative roughness (e/D) and Reynolds number (R), as shown in Figure 9. For water at 60° F, simultaneous solution of the Williams-Hazen equation and Equation 7 gives

$$f_{WH} = \frac{1{,}060}{C_{WH}^{1.85} R^{0.15} D^{0.015}} \cong \frac{1{,}060}{C_{WH}^{1.85} R^{0.15}} \tag{8}$$

Superposed on the general resistance diagram, Figure 9, are lines for various Williams-Hazen C-values. A 12-inch and a 48-inch diameter represent extremes for typical arterial network sizes. Because a head loss exceeding 10-feet per mile or 2-feet per thousand on the average can seldom be tolerated, this criteria was used to establish the upper limit for the two representative diameters. Because a head loss of 0.2-feet per thousand cannot be accurately determined in field measurements and is well below the level of design significance, it was used as a lower limit for the two diameters. Referring to Table 2, it may be noted that if equal values of f are taken at 0.2-feet per thousand, the Williams-Hazen equation f-values are progressively lower than the "Moody Diagram" for smaller C-values. Corresponding differences in relative roughness are also shown. Because C-values are normally acquired for moderate rates of flow, the apparent departures in Table 2 are somewhat exaggerated.

Arterial mains must function at a high level of efficiency. Cast-iron pipe is normally installed with a cement lining, surface smoothness of concrete pipe is carefully controlled, and a variety of coatings are applied to steel pipe[36] to insure best performance. Hinds[37] has transcribed the summary of Colebrook[38] on lined pipes, reproduced here in Figure 10. It is to be noted that lined pipes, in good condition, strongly tend to satisfy the hydraulically smooth pipe relation, which is closely approximated by

$$\frac{1}{\sqrt{f}} = 2 \operatorname{Log} \frac{R\sqrt{f}}{2.51} \tag{9}$$

Recall that the Williams-Hazen equation is closest to the general resistance diagram at higher values of C. We may conclude that because arterial mains are usually lined, and lining quality is usually maintained, the Williams-Hazen equation is particularly applicable to arterial network design.

LOCAL LOSSES

The general resistance diagram applies only to a rifle-barrel geometry and does not take into account or include any allowance for local losses induced by bends, tees, valves, crosses, etc., and surface irregularities at joints. Local losses can be represented by

$$h_L = K \frac{V^2}{2g} \tag{10}$$

where h_L is the local head loss in feet due to the particular fitting, V is the mean velocity (here it will be taken as the pipe velocity) and K is a constant for most practical cases. Recall that field measurements of head loss for C-value determina-

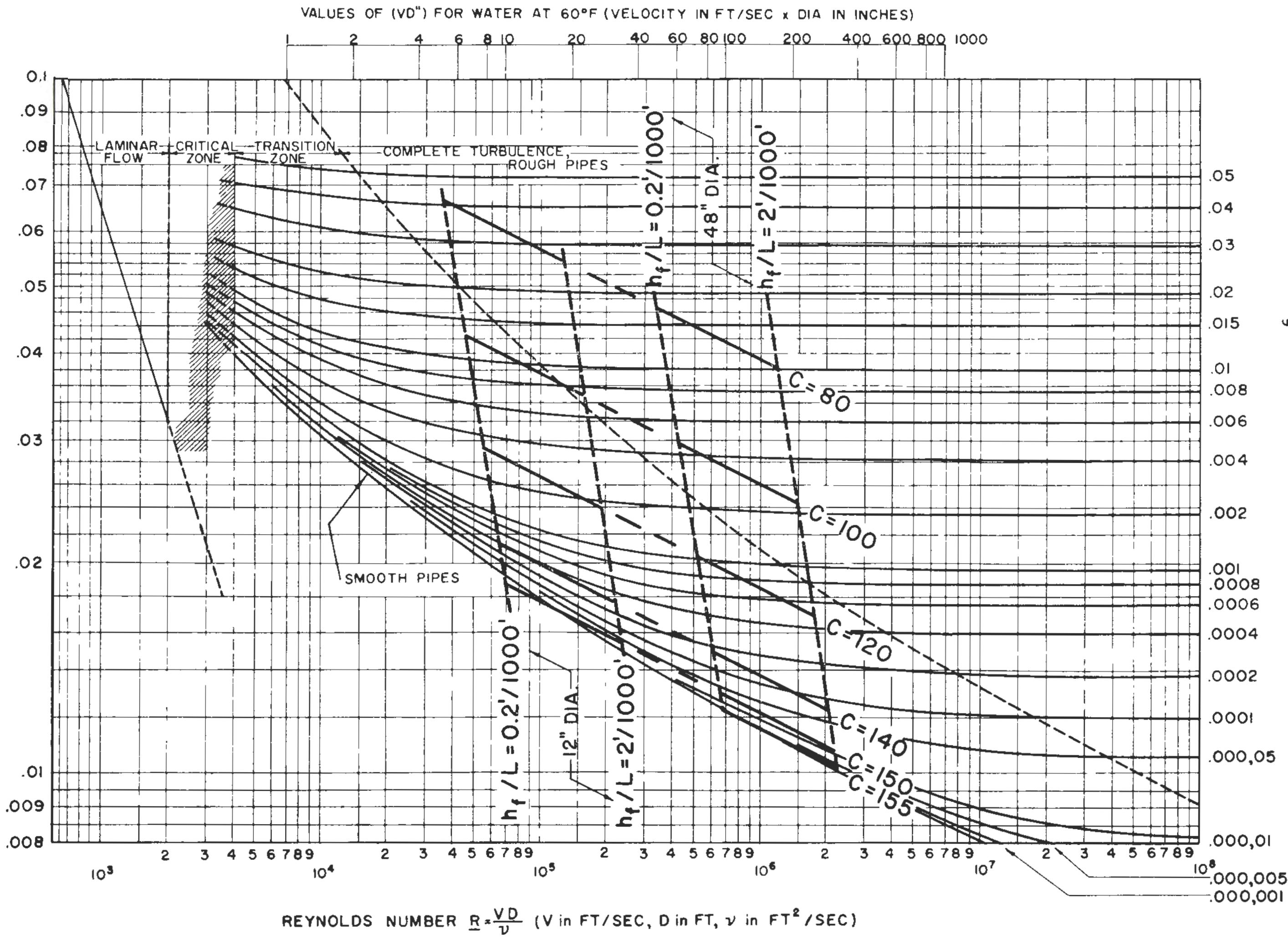

Figure 9. General resistance diagram for commercial pipes ("Moody Diagram")

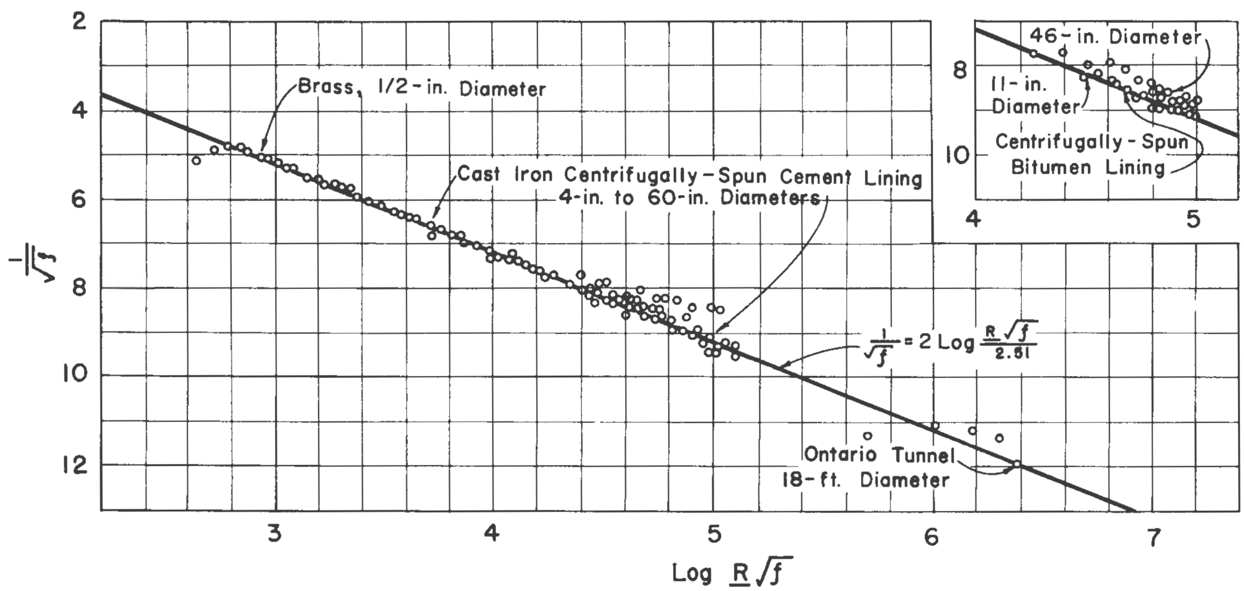

Figure 10. Selected field data for lined commercial pipe vs. "smooth" pipe equation

tion almost invariably include a component due to local losses. What is the effect of local losses on "observed" C-values? Let the total loss over a given reach of pipe be designated by Σh, let the friction coefficient be f_1 for the measured loss ignoring the presence of local losses, and let the true value for pipe friction alone be f_0. For the given reach, ignoring local losses,

$$\Sigma h = f_1 \frac{L}{D} \frac{V^2}{2g}, \text{ or } \frac{\Sigma h}{V^2/2g} = f_1 \frac{L}{D} \tag{11}$$

Allowing for local losses,

$$\Sigma h = f_0 \frac{L}{D} \frac{V^2}{2g} + \Sigma K V^2/2g, \text{ or}$$

$$\frac{\Sigma h}{V^2/2g} = f_0 \frac{L}{D} + \Sigma K \tag{12}$$

For a particular measurement, Σh and V would be the same for both cases and f_1 would be the *apparent* value:

$$f_1 \frac{L}{D} = f_0 \frac{L}{D} + \Sigma K \text{ or,}$$

$$f_1 - f_0 = \Sigma K/(L/D)$$

and from Equation 8, for water at 60° F,

$$\frac{1{,}060}{R^{0.15}} \left(\frac{1}{C_1^{1.85}} - \frac{1}{C_0^{1.85}} \right) = \Sigma K/(L/D) \tag{13}$$

Here $R = R_0 = R_1$ since the same V and D are involved in the comparison. Equation 13 was solved using various $(L/D)/\Sigma K$ and C_0, Table 3. It should be noted that the presence of a large aggregation of local losses has least effect where the pipe friction loss is larger ($C_0 = 80$) and an appreciable effect where the pipe friction loss is smaller ($C_0 = 140$). This is simply a matter of the relative weights of numbers. Because arterial mains have, or should have, high C-values one might misinterpret the cause of a lower than expected C and blame it on the quality or deterioration of the lining. In network balancing the C values used are normally those obtained directly from field tests and hence are apparent values which include the influence of whatever local losses were present. Neither all the arterial mains nor all segments of those mains calibrated are accessible for field head loss measurements. When a measured C is assumed to apply to another main of the same diameter laid in the same

Table 3

Apparent Values of C for Pipes with Locol Losses Due to Valves of Fittings

$(L/D)/\Sigma K$	Apparent Values, C_1, at $R = 3 \times 10^5$. $C_0 = 80$	$C_0 = 100$	$C_0 = 120$	$C_0 = 140$
50	66	76	86	92
100	72	88	100	109
200	76	92	108	120
500	78	96	115	132
1,000	79	98	116	135
2,000	80	99	119	137
5,000	80	99	119	139
10,000	80	100	120	140

Table 4

Apparent Values of C for Pipes with Local Losses Due to Valves and Fittings

	Apparent Values, C_1					
	$C_0 = 80$			$C_0 = 140$		
$(L/D)/\Sigma K$	$R = 10^5$	$R = 3 \times 10^5$	$R = 10^6$	$R = 10^5$	$R = 3 \times 10^5$	$R = 10^6$
50	68	66	65	96	92	87
100	73	72	71	112	109	105
500	78	78	78	133	132	132
1,000	80	80	80	137	135	135
5,000	80	80	80	140	139	140

year the assumption is reasonable only when the local losses over a corresponding length are reasonably similar.

Table 3 was prepared using $R = 3 \times 10^5$. In Table 4 are apparent values C_1, for $R = 10^5$ and 10^6 and C_0 of 80 and 140. This range of R covers a good part of the total superposed plot in Figure 9. Again, only the higher C_0 is particularly affected, but the influence of the magnitude of local losses far outweighs the relatively small difference from one R to another.

CHOICE OF EXPONENT, *m*

On the other hand, the contribution of local losses to the total loss in arterial mains is small compared with grid mains. Arterial mains have limited access for some of the same reasons as for express highways. Figures 6 and 7 serve as a reminder of the many fittings which exist in grid mains. The ferrules of service connections might and often do project into the interior of grid mains, adding further to the local losses. The flow coefficients for grid mains are seldom as high as for arterial mains because of the presence of much higher local losses; and they have a much lower priority for relining. Referring to Figure 9 it may be noted that the head loss characteristics of small grid pipes with a C of 100 or less would be better approximated with an m of 2.00.

With the McIlroy Analyzer the value of m for individual mains can be arranged to fall anywhere between 1.85 and 2.00 by using a coefficient slightly higher or lower than the one desired. With a digital computer the Cross method cannot be applied to mixed values of m without substantial modification of programs now in use. Iteration using mixed values of m would require more machine time, and would lead to greater potential information errors, assuming the use of mixed values would not obfuscate convergence mathematically. Unquestionably, use of $m = 1.85$ or any other non-integer requires more storage capacity and longer computer time than for $m = 2.00$.

In general, there appears to be no logical reason for avoiding the square relation with grid networks. For arterial networks, if the C-values used in digital computer balances are nothing better than gross approximations there appears to be no valid reason for investing extra time and funds in a non-integer value of m, namely the traditional value of 1.85, rather than 2.00. When $m = 1.85$ is used for arterial networks, it is tacitly implied that a majority of the arterial mains have or will have linings in good condition.

Kincaid[39, 40] has detailed a summary of considerations which should be investigated in preparing data for a network balance. Reasons why grid loads for design can be consolidated at grid intersections have been advanced.[41] Some of the technical considerations for grid network balancing have been reviewed in terms of modern computer applications.[42]

SYSTEM BALANCING

The overwhelming emphasis in publications dealing with analysis of systems has been on network balancing. In the instance of a service district with a single sendout (source) and no elevated storage, proper utilization of network balances should lead to an acceptable system analysis directly. For multiple sources which operate under a variable head (pumping stations and ground reservoirs) with or without elevated storage, or even a single source with elevated storage, system balancing becomes more complex. In all but the simplest case, a single sendout without equalizing storage, network balancing is merely a means to an end.

A given system can be reduced to the hydraulic characteristics of its four basic components: pipe network, pump performance, pumping station, and suction source, and storage. In design, these must be reconciled and integrated with design loading schedules. "A comprehensive system analysis is required to insure that the benefits claimed for the design recommendations offered are physically attainable."[43] Because a system will operate under one combination of demands and hydraulic component characteristics by no means assures that other combinations necessarily will be operable. Compatibility cannot be assumed until complete system balances are made. A system balance is essentially an hour-by-hour simulation of an anticipated operation schedule. The "most economical design" may be a gross approximation in the absence of a thorough system balancing analysis.

In a previous section, mention was made of the common assumption that local network demands (loads) fluctuate in direct proportion with the total network demand, a condition called hereafter *proportional loading*. It has been demonstrated[43] that

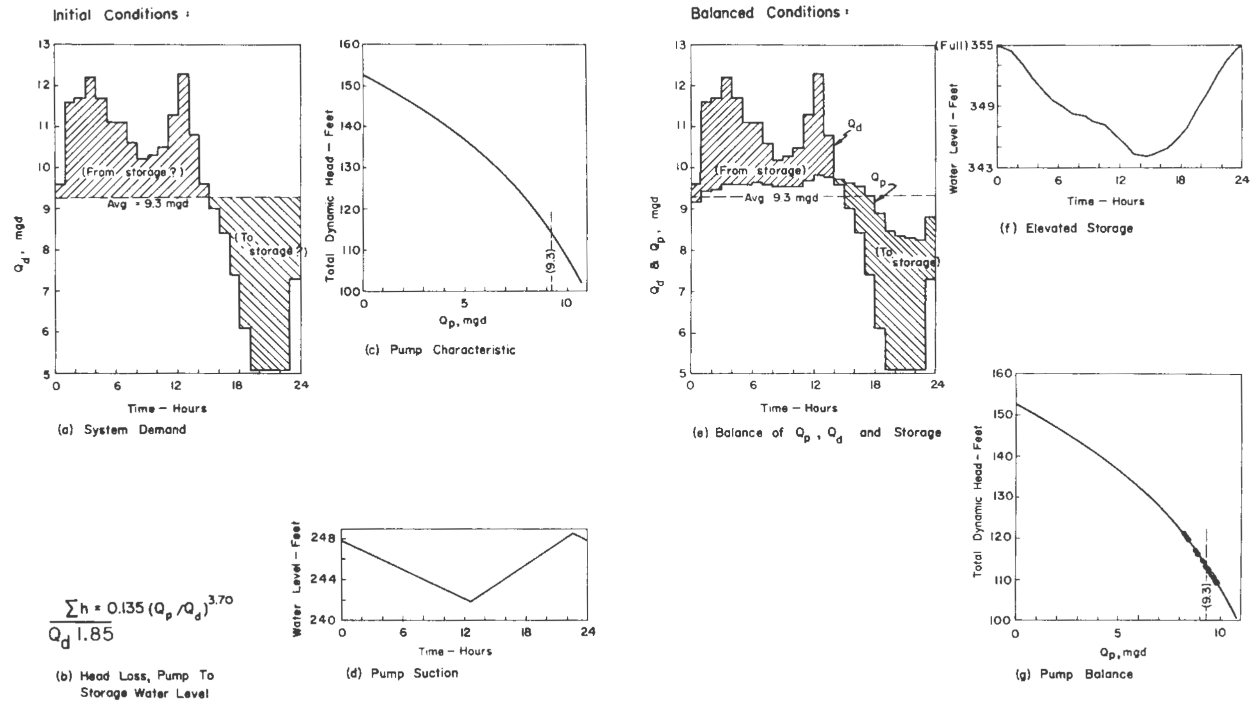

Figure 11. Example of storage-network-pump balancing

the head loss of a complex system network can be reduced to a simple equation under proportional loading conditions:

$$\Sigma\, h/Q_d{}^m = \Phi\ (Q_p/Q_d)^n \qquad (14)$$

where Σh is the head loss between a sendout and a point in the district (such as an elevated storage site), Q_d is the network loading or demand rate and Q_p is the sendout rate at the point from which Σh is reference. Only two network balances are required to determine Φ and n. For a single sendout and no equalizing storage $Q_p = Q_d$, and only one network balance is required to determine Φ.

An approximate system balance for 24 hourly demands for the district arterial network shown in Figure 8 was made some time ago,[42] without benefit of Equation 14. This balance was repeated using Equation 14 recently,[43] but a minor simplification was incorporated for tabular presentation. The values from Table 13 of reference (43) have been plotted in Figure 11. One of the principal objectives in the utilization of elevated storage is maintenance of near-uniform pumping. Each hourly demand was balanced by trial in sequence. Over sixty trial combinations were needed for the balance. Because each trial involved a unique combination of variables, the head loss (here to the elevated storage) for each trial differed. Without Equation 14 a considerable number of network balances would have been required to approximate the exactitude in system balance achieved, but only two network balances are required to determine Φ and n in Equation 14.

The Philadelphia Water Department has under development a system balance digital computer program which will incorporate Equation 14 and subroutines for pump characteristics and pumping station suction loss. Pumping station hydraulics will be separated because pump characteristics and station losses are nonlinear independent design factors. The comparative influence of diverse pump characteristics and storage capacities in the balancing of given systems will be investigated under a variety of demand schedules. The principal objective of the study will be the determination of basic criteria for optimum utilization of equalizing storage and pumping facilities. This study would not be practicable in the absence of the generalized network parameter, Equation 14.

From the standpoint of system balancing it makes no difference whether balanced network results are obtained by means of McIlroy Analyzers, calculating boards, or digital computers. A McIlroy Analyzer could be used directly in a system balance using auxiliary computations to determine combinations needed, but this is an involved procedure. If the proportional loading principle can be exploited, the obvious and preferable device for system balancing is the digital computer. Several combinations of alternative hydraulic components should henceforth always be investigated for system designs. This is an almost entirely new and very important refinement, and the digital computer is the present obvious choice for this task. If and when auxiliary equipment is provided on McIlroy Analyzers for automatic programming of sendouts and storage it will then become the preferred machine for system balancing because of its direct simulation feature. For the present, the McIlroy Analyzer is the preferred design tool for network balancing and design, and the digital computer is the preferred tool for system balancing.

DIGITAL COMPUTER USERS' LIBRARY PROGRAMS

In an effort to obtain current information for this paper, questionnaires were mailed to the program librarians of the twelve vendors of medium and small digital computers cited by Merritt.[44] The lower purchase or rental costs and ubiquitous distribution of this class of digital computer, together with the general availability of the comprehensive descriptions given by Merritt, prompted this choice. An exception was made to include a small computer with a medium capacity made by Packard-Bell and introduced only a month before publication of Merritt's article. This machine is one of the new generation of compact, low-cost, medium capacity, high speed, solid-state (no gaseous transmission elements) devices. While the bases for selection were somewhat arbitrary, the reader should obtain a good idea of the availability of programs for network balancing in users' libraries from the replies.

The questionnaire was accompanied by a definition of boundary conditions, the equations to be solved and an example of a balanced elementary network.[27] Copies of the flow charts given by Hoag and Weinberg[25] and by Hamblen[27] were also included.

Questionnaire Form

This questionnaire was sent to 12 program librarians.

1. Is a program for solution of the subject problem available in your users' library?
2. Has the program been published or is it available to the public at large? If published, please cite reference.
3. Machine model number and special auxiliary equipment needed?
4. Program written by whom or for what firm?
5. Is the "Hardy Cross Method" incorporated in the program for iterative convergence? Other?
6. Does the program permit use of mixed powers of m in $h = kQ^m$, or is a single value of m used? If a single value, is m assigned an absolute magnitude in the program, such as 1.85?
7. Is convergence directed towards a maximum limit of imbalance in any loop in terms of a head loss Σh, or in terms of a flow ΔQ?
8. Does the program incorporate any special features which facilitate convergence or minimize number of iterations required?
9. Are loop balances computed for individual interior loops only, or is there allowance for checking composite loops (routes encompassing two or more interior loops) or external loops?
10. Is a flow chart (or diagram) available?
11. Do you know any particulars or efficiency or performance of the program? That is, from experience have results been satisfactory; is convergence achieved in a reasonable number of iterations, etc.?

Replies to the Author's Questionnaire

Bendix Computer Division, 1000 Connecticut Ave., N.W., Washington 6, D.C. Inquiry referred to, and reply made by John T. Potts, Jr. of Reynolds, Smith and Hills, Architects and Engineers, 4019 Boulevard Center Drive, Jacksonville 1, Florida.

1. Yes, the program is available to the G-15 Users' Exchange Organization Library. (Users' Project No. 215-A.)
2. To my knowledge it has only been published in the above library. It is only available to participating members of the Exchange Organization.
3. Bendix G-15D computer; no auxiliary equipment required.
4. The original program was written by Mr. George R. Blanke, Midwest Computer Service, Inc., 316 East Wood Street, Decatur, Illinois. Revision I was written by myself at Reynolds, Smith and Hills. The revision was mainly a matter of recoding in Intercom 500X system which has the effect of making operation simpler than the original Intercom 101 version.
5. The "Hardy Cross method" is used.
6. $m = 1.85$.
7. The complete correction cycle is repeated if any loop had a correction of flow (ΔQ) which exceeds a stated tolerance factor.
8. No.
9. Only interior loops are balanced.
10. Yes.
11. It is difficult to make estimates of time required to solve a particular problem. This program has proven to be satisfactory for our use; however, it would not be very difficult to improve its efficiency by a factor of about 5. We would do this if a heavy demand for the program develops. Actually, I believe that Midwest Computer Service have written a more recent program for the G-15 which is much faster than this one. However, I believe it is unpublished.

Burroughs Corporation, 460 Sierra Madre Villa,

Pasadena, California. Reply by A. Paul Oleson, Professional Services Department.

1. Burroughs has no network analysis programs for water service.* It has one program for the Burroughs 205 for network analysis of gas distribution systems.

2. The program described was published as a company bulletin several years ago, but it has since been withdrawn.

3. Burroughs 205, automatic floating point, paper tape input, Flexowriter output.

4. Program was written by Jack Warga for Burroughs.

5. The Hardy Cross Method was not used as such. A Newton-Raphson Method[29] was employed for iterative convergence.

6. The program used a single specified value of m.

7. Convergence was directed toward maximum relative limits on ΔQ.

8. The program contained no forcing procedures.

9. The loop balances were restricted to interior loops only.

10. Flow charts are available. These would appear to have little value since the program is rather elementary.

11. We do not have data on the efficiency of the program.

Packard Bell Computer, 1905 Armacost Ave., Los Angeles 25, California. Reply by Dale C. Wagner.

1. Yes, a Water Distribution Program is available for use with the Packard Bell PB 250 computer. This program was originally written as a Gas Distribution Program and a few minor modifications have been made to it to permit its use for water distribution.

2. No, this program has not been formally published. However, it is available to users of the PB 250.

3. Any Packard Bell PB 250 with at least eight lines of memory can be used for this solution. Each line of memory consists of two hundred and fifty-six 21-bit words.

4. This program was written by the above for the Packard Bell Computer Corporation.

5. A modified "Hardy Cross" technique is the basis for iterative program convergence.

6. Yes, the program does permit use of different powers of m value in the evaluation of feet of head pressure drop. This value is not loaded on the data tape itself but is a manual change through the Flexowriter.

7. Convergence is directed toward a maximum limit of 0.01 feet of head drop.

8. Convergence is facilitated by including a factor of 0.5 in the ΔQ. This program is very tightly optimized to obtain maximum speed of operation.

9. Loops may be balanced as individual interior loops or as composite loops. If composite loops are used speed of convergence is increased.

10. Yes, for Gas Distribution. A Water Distribution Program write-up is not yet complete but will be nearly identical to that for Gas Distribution.

11. To give you some idea of the speed of computation — a 14-leg gas system involving ten loops has been performed in 90 seconds. Sixteen iterations were required by the routine to affect required convergence.

Addendum to Merritt's outline,[44] for the Packard Bell PB 250:

Vacuum tubes or transistors	Transistors
Input Equipment*	MT, PT, PC, T
Output Equipment*	MT, PT, PC, T, LP
No. digits per word	22
Addresses per instruction	1
Instructions per word	1
Internal memory	Delay line
Memory capacity - words	2320
Average access time microseconds	1500
Decimal point	Fixed
Alpha numeric?	Yes
Arithmetic registers	3
Index Registers	Yes
Purchase price	$40,000
Monthly rental	$ 1,200

Control Data Corporation, Computer Division, 501 Park Avenue, Minneapolis 15, Minnesota; reported by Mr. Harold A. Theiste, Project Coordinator:

1. The program currently has not been included in our CO-OP library, but it is intended that it will be. It is a part of our service bureau library.

2. A general description is available, but the program to which it refers has not been published. The program is applicable to water systems which do or do not include pumps and storage tanks. The curve data of head as a function of flow for pumps and elevated storage can comprise part of the input.

3. Equipment configuration used is:
   a. 1604 Computer**
   b. 1607 tape unit
   c. 1610 card reader
   d. 1606 line printer

4. The program was written by the Computation Services Department of Control Data Corporation using Fortran.

5. The program is based on the Hardy Cross method.

6. The formula used for head loss is $h = KQ^{1.85}$, however, modification to use mixed exponents is possible.

7. The convergence criteria is in terms of Σh imbalance in a loop, and is variable dependent on the desires of the user.

8. The program does not include any devices for minimizing the number of iterations required for convergence.

9. The loops are set up by the engineer and can be of any configuration as long as they are closed.

10. The final flow chart is not currently available.

11. The program has provided very good results in relatively few iterations. Average run time for a network containing 200 pipes is about 4—5 minutes. This time could be improved; however, for the application, it is not considered necessary.

International Business Machines Corporation, Data Processing Division, 230 South 15th Street, Philadelphia 2, Pennsylvania. Reply by J. M. Curley, Local Government Representative.

1. Yes. Title: "Distribution of Water Flow in a Pipe Network."

2. Available through DP Program Library Services, New York.

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* "We are writing programs in ALGOL for the Burroughs 220 and the B5000 for network analysis using the procedures described by Warga. These will include a choice of several options for the resistance formula."

* MT—magnetic tape; PT—paper tape; PC—punched cards; T—typewriter; LP—line printer.

** The Control Data Corporation 1604 is a large-scale computer. We have not attempted to use our small-scale 160-A computers on the problem since we are able to obtain results faster and at a comparable cost on our large-scale system. However, we do anticipate writing a similar program if the need develops on our 160-A computer.

3. Minimum 1620 and with paper tape input and output. Can be recompiled for card equipment.

4. Author: C. Bartholet, IBM, Boston.

5. Hardy Cross Method is incorporated for iterative convergence.

6. $m = 1.852$ is used. No variation of Hazen-Williams Coefficient is permitted.

7. Convergence is directed towards a specified limit in terms of ΔQ.

8. Yes. Accuracy (tolerance) of flow increment ΔQ can be changed by operator.

9. For a maximum system of 150 pipes and 67 loops, composite loops are also checked.

10. Flow chart is available with program write-up. For authorship and credit, inferential use is permitted.

11. Computation times approximately 1 second per pipe per iteration.

Royal McBee Corporation, 850 Third Avenue, New York 22, New York. The following information was volunteered by E. W. Miller, President, Technical Advisors, Inc., Municipal Court Building, Ann Arbor, Michigan, in default of a reply from the vendor.

1. Yes, two programs are available for the LGP-30 through POOL, the LGP-30 Users Organization.

2. One of the programs (M5-220) has been published for members of POOL; the second (M5-147) which is basically the program we use, is available to POOL members on a "loan" basis. The specific difference between these programs has not been evaluated; however, both programs can handle in excess of 1,500 pipe segments or approximately 250 loops.

3. Both programs require only the basic Royal McBee LGP-30 Computer.

4. M5-220 was written by D. M. Gilbert, Public Service of Colorado, Denver, Colorado. M5-147 was originally written by the Royal McBee Corporation. We modified the original program to permit the use of up to five pumps and/or reservoirs in the system. Orr Engineering Company, Minneapolis, Minnesota, made further modifications to enable the operator to operate on any individual loop.

5. The "Hardy Cross Method" is used in both programs.

6. M5-147 uses $m = 1.85$; however, a simple program change permits use of other values of m, if desired.

7. Convergence is directed towards a maximum limit of imbalance in any loop in terms of head loss. (M5-147).

8. The operator can easily transfer to a particular loop or group of loops to expedite a "balance." (M5-147).

9. Only the loops that are set up can be checked for head balance; however, loops encompassing two or more interior loops can be set up. We have found that convergence is speeded up by always incorporating each pipe segment in at least two loops. (M5-147).

10. A flow chart is available for M5-220; however, no flow chart is available for M5-147.

11. To date, we have been able to achieve convergence with M5-147 within ten iterations.

A few additional comments: As an electronic computer service bureau staffed principally by engineers and specializing in engineering computations, we are firmly convinced that the analysis of water distribution systems is one of the more powerful applications of electronic computers. Unfortunately, most computer programs for engineering applications merely adopt standard manual methods — using the computer as a high-speed calculator, rather than as a tool for performing a better overall job. Within the limitations of equipment, personnel, and practical economics, we believe our organization is making some headway in this direction. For example, the incorporation of pump curves (or station curves) and reservoir elevations permits the solution of a "dynamic," multiple-input system rather than the "static" system normally utilized, where the setting of one pressure automatically establishes the pressure throughout the system. The computer has also been programmed to output the residual pressure (in p.s.i.) at various points in the system when elevation data is provided. Additional improvements are anticipated when we re-program for the larger Royal McBee RPC-4000 Computer.

INDEPENDENT PROGRAMMING

Attention has been called to the availability of digital computer services for network balancing by correspondence. There is a large number of computing service or data processing centers throughout the country. A number of these have written their own programs for network balancing or have used or modified users' library programs for their particular machines. Unless these centers have had experience with several network balances it may be difficult to obtain from them a dependable cost estimate for a specific series of balances. Contracting for computation service can be a harassing experience if the service center has only a limited familiarity with the program to be used.

Engineers using machines owned or rented by their employer have often found that users' library programs require some degreee of modification. Computers, like automobiles, come in basic models but with a variety of optional accessories. A program written for a given machine model with given accessories may be completely incompatible for the same model with different accessories. While many engineers depend on professional programmers, the number of engineers capable of doing their own programming is steadily increasing. In not too many years most engineering students will have had some training in computer problem solving. A new introductory course on computers for second-year engineering students is being established at the University of Illinois. In an article entitled "Engineering Students Must Learn Both Computing and Mathematics," Forsythe[45] submits that "Today, with ALGOL, an engineer can learn to write his own programs in ten hours of study. Programs can be written perhaps fifty times faster than formerly." ("ALGOL is a standard language for the communication of mathematical and logical algorithms.") Analagous progress has been attained in the introduction of FORTRAN and other computer coding languages. The engineer who has hesitated to program his own work at least can now learn quickly to read and check a program written for him in one of the new languages.

CONCLUDING REMARKS

The major share of capital investment in water works has been in distribution networks. Billions of dollars have been invested in existing distribution systems and the cost of new construction in the United States probably aggregates well over a billion dollars per year. Analysis and design of distribution systems has too often been less extensive than for treatment facilities. With the availability of modern computing devices there is no longer any excuse for perfunctory design or arbitrary methods of analysis. This is not to suggest that an extremely high level of exactitude can be achieved. Future total system demands, future friction coefficients and the relocation, proportion and variations of loads for the future are necessarily all judgment projections. The accuracy of network balances, regardless of type of machine employed, is of the order of the accuracy of the data fed into the machine. The ultimate value of the results obtained depend entirely on their proper utilization and interpretation by the design engineer. There is no such thing as a perfect design for which all future exigencies and trends have been anticipated. A good design contains a degree of flexibility and remains a good design only so long as it is continuously reviewed, revaluated, and modified to conform with obvious departures from previous projections. The application of statistical methods to projections of demands for use in distribution design has been retarded by the incomplete acceptance of a need for thorough system balance analyses.

Adams has reviewed several analog methods for network balancing[46] and outlined recent experiences in Great Britain using a digital computer.[47] A direct analog for network balancing has been developed by the Montan-Forschung firm in Germany.[48] Satisfaction of Equation 5 for each branch is approached in discrete steps by means of a series of linear resistance values automatically ordered by an electronic circuit. Each electronic resistance circuit can be manually set at any desired reference R, and is thereby capable of representing a full range of Fluistor values. However, the relatively larger size and higher cost of the circuits would probably confine the practicable size of the analog to a small- or medium-network capacity machine.

ACKNOWLEDGMENT

The information furnished by vendors and users is gratefully acknowledged. Mr. J. V. Radziul, Chief, R. and D. Unit, Philadelphia Water Department, Philadelphia, Pennsylvania, provided the photos for Figures 1 and 2, prepared Figures 6, 7, and 8 and furnished supporting information.

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PIPE MATERIALS, COATINGS, AND JOINTS FOR WATER DISTRIBUTION SYSTEMS

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INTRODUCTION

Engineering practice in the application of the many kinds of pipe materials, protective coatings, and joints available for use in water distribution systems varies considerably in different parts of this country. In most cases it is found that practice at specific locations is based on actual experience and is the result of a selective choice of the kinds of materials that have proven satisfactory and reliable by trial and error methods. Materials which have long experience records of satisfactory performance in some areas may be unsatisfactory in others because of local conditions such as corrosive soils or aggressive water. For this reason it is difficult to make definite recommendations concerning pipe, coatings, and joints which can be guaranteed to be satisfactory under all local conditions encountered throughout the United States. In this discussion, only the materials ordinarily used in water distribution systems will be discussed, along with their advantages and disadvantages for certain given conditions. Because this subject is quite broad in scope, it will be impossible to cover all of the particulars of the various materials; therefore, the discussion will be limited to materials which are commonly used in practice. The details of the materials will not be described, except by referring to standard specifications which are listed among the References.

There are four basic types of pipe used in water distribution practice: (1) cast iron, (2) asbestos-cement, (3) steel, and (4) concrete. The user of these four basic types has a choice, in almost every case, of several types of joints. He also has various combinations of protective coatings and linings to choose from. Since the type of joints and protective coatings and linings commonly used with each type of pipe are, in general, peculiar to the type of pipe, they will be discussed along with the pipe material in each case.

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CAST IRON PIPE

Cast iron pipe is the most commonly used material in water distribution systems, especially in the smaller sizes. It is available from three basic manufacturing processes: pit cast,[1] centrifugally cast in metal molds,[2] and centrifugally cast in sand-lined molds.[3] Pipe is available in all sizes by the pit cast process, but is limited in size to 24 inches by the centrifugally cast in metal molds method, and to 48 inches in the centrifugally cast in sand-lined molds method. The standard specifications for pit cast pipe are based on a quality of iron having a tensile strength of 11,000 p.s.i. and a modulus rupture of 30,000 p.s.i.; the quality of iron under the standard specification for centrifugally cast pipe has a tensile strength of 18,000 p.s.i. and a modulus rupture of 40,000 p.s.i. However, pipe by special order is available in higher quality cast iron, and it can now be obtained in ductile iron in sizes through 24-inch with a maximum tensile strength of 80,000 p.s.i. and a yield point of 60,000 p.s.i. Of the various types of pipe materials available, cast iron is the only one for which there is a standard for the design of the pipe which takes into consideration both internal pressure and external loads.[4] This standard is based on many years of test work at Iowa State College and other universities, and is now universally accepted as the basis for design of all cast iron pipe in this country.

There are three basic types of joints commonly used with cast iron pipe in water distribution service: bell and spigot, mechanical-bolted, and boltless-gasketed. The bell and spigot joint is covered by the basic pipe specifications and the mechanical-bolted joint is covered by a separate ASA standard.[5] The boltless-gasketed joint, a relatively recent development of the cast iron pipe industry, is available as various manufacturers standards such as American Cast Iron Pipe Company's "Fastite," James B. Clow & Sons' "Bell-tite," and U.S. Pipe and Foundry Company's "Tyton" joints. For many years the bell and spigot joint was used universally in water distribution systems with a braided jute packing and a lead filler. Later, because of the cost of lead, a substitute was used for the joint filler. This consisted of a mixture of sulfur and silica sand. This filler was considerably more economical than lead and proved satisfactory in many systems. However, a number of users of the sulfur-silica filler encountered considerable difficulty with bell failures. These failures were attributed to either corrosion, expansion of the filler in the joint, or a combination of both. In some soils, bacteria apparently combine with the sulfur in the filler to form by-products or compounds which are corrosive to iron and also cause excessive expansion of the joint filler. Ring tests have also proven that sulfur-silica filler (if kept continuously saturated) will expand so that excessive stresses develop in bells of large-diameter pipe. For the previously mentioned reasons, the use of sulfur-silica filler has been almost entirely abandoned by most water departments. The mechanical-bolted joint was commonly used after the sulfur-silica filler was found unsatisfactory. The mechanical-bolted joint has proved to be very satisfactory. However, this joint has now been replaced, to a large extent, by the boltless-gasketed type. It has been replaced, except for fittings and valves, by the boltless-gasketed joint primarily for economic reasons since the boltless-gasketed joint is much easier to install and is lower in initial cost. Many systems have used, and are using, cement joints. However, cement as a joint filler (because of its inherent lack of flexibility in allowing for pipe movement and settlement) has not gained wide acceptance. The packing most commonly used today in bell and spigot joints is of three types: molded or tubular rubber rings, asbestos rope, or treated paper rope. The specifications covering the materials for the make-up of bell and spigot joints is covered by standard specifications.[6]

In addition to the three basic types of joints previously mentioned, flanged joints are commonly used when connecting to valves and specials. In certain instances, *Victaulic* or *Dresser* couplings are also used.

For many years, the only coating and lining available for cast iron pipe was that obtained by dipping the hot casting in a bath of coal tar varnish. However, cement-mortar linings, which have been available for about thirty years, are now commonly used by most water distribution systems because they have proven that they will maintain a high flow coefficient while preventing tuberculation of the pipe wall. Cement-mortar linings are also available under a standard specification.[7] They vary in thickness depending upon the size of the pipe. The standard cement-mortar lining specification calls for a ⅛-inch thickness for sizes 4 inches through 12 inches, 3/16-inch thickness for sizes 14 through 24 inches, and ¼-inch thickness for sizes 33 through 48 inches. Cement-mortar linings having one-half the thickness of the standard lining are available from most manufacturers under a manufacturer's standard. The thinner linings are permitted by many users because they have been found to accomplish essentially the same purpose as the thicker standard lining. The thinner lining can be obtained at no additional cost in straight pipe. The standard lining, however, will cost extra.

Cast iron pipe has proven to be dependable and reliable in most water distribution systems because it is inherently corrosion resistant to most soils and waters. It has an extremely long service record. The first record of its use was in Versailles, France, between 1664 and 1688. The first cast iron pipe used in the United States was in 1804 in the Philadelphia system, which I understand, is still in use. No doubt, all of you have seen the advertisements of the cast iron industry summarizing the number of cities in the United States which have cast iron mains in service for a period exceeding 100 years. The list of these cities is impressive, and from these records it can be concluded that cast iron pipe will have an almost infinite life in locations unaffected by soil corrosion or electrolysis. The principal disadvantage of cast iron pipe is its inherent rigidity and lack of ductility. Because of this, some utilities now limit the use of cast iron pipe to the smaller sizes. Some cities set the maximum size for cast iron pipe at 16 inches, and others permit its use through 24-inch sizes. The lack of ductility in cast iron makes it especially vulnerable to soil movements, settlement, or shock load. Many engineers now feel that it is good practice to limit the size of cast iron pipe to those sizes which will incur limited water damage or interruption in service in the event of a line break.

ASBESTOS-CEMENT PIPE

The use of asbestos-cement pipe has gained general acceptance in a number of water distribution systems, especially in those areas where corrosion from the surrounding soil or water is a problem. It is available under standard specifications[8] in sizes 4 inches through 36 inches. At the present time, there is no accepted design method available for asbestos-cement which takes into consideration the combined effect of internal pressure and external load, although the standard specifications do stipulate the minimum internal bursting pressure which the pipe shall be capable of withstanding and the minimum three-edge bearing strengths. The pipe is available under standard specifications in Classes 100, 150, and 200. These classes correspond to the internal pressure for which the pipe is designed. The user of asbestos-cement pipe, however, should be cautioned that these classes do not correspond to those for cast iron pipe. When using asbestos-cement pipe, allowances should be made for the combined effect of internal pressure and external loads.

The joint ordinarily used with asbestos-cement pipe is an asbestos-cement sleeve with two O-ring rubber gaskets. Asbestos-cement pipe is not ordinarily coated because the pipe material is considered to be basically resistant to corrosion in most waters and natural soil conditions. It is subject to corrosion, however, in highly acid or highly sulfate-alkaline soils.

Asbestos-cement pipe is considered advantageous in most locations where corrosion or electrolysis is a problem. Another advantage is its ability to maintain a high flow coefficient throughout its life. Asbestos-cement pipe is also relatively light, which facilitates handling and laying, and its joints are easy to assemble. However, it is considered by many engineers to be basically not so strong as some of the other pipe materials available. Trouble with breakage has been reported when it is used in tight soils subject to high shrinkage due to changes in moisture content. Under such conditions it is advisable to install the pipe with a granular embedment.

STEEL PIPE

Steel pipe is available as standard mill pipe[9] and as shop fabricated pipe[10] with various combinations of internal linings and exterior coatings. It is ordinarily designed for the internal working pressure plus an allowance for water hammer based on about one-half of the yield strength of the steel, and a limiting maximum pipe deflection which will not damage the interior lining or exterior coating. The practice of the author's firm is to limit the maximum deflection of steel pipe with either a cement-mortar or coal tar lining to two per cent of the diameter using the formula developed by Spangler.[11] This formula takes into account the vertical load on the pipe, the modulus of elasticity of the pipe material, the moment of inertia of the pipe wall, and the passive resistance of the enveloping soil. Steel pipe is inherently flexible as opposed to the rigidity of cast iron, asbestos-cement, and concrete pipes. Its ability to withstand external loads in the larger sizes is dependent to a large extent upon how the pipe is bedded in the trench. For this reason, the design of the pipe must take into consideration the kind of bedding which will be obtained in the field. If this is not done excessive deflections or possibly even collapse may occur from external trench and live loads.

Joints commonly used with steel pipe are: mechanical (*Dresser*), bell and spigot with rubber gasket, *Victaulic*, and welded. Probably the most commonly used joint with steel pipe is the mechanical bolted type (*Dresser*). Welded joints are used in the larger pipe sizes. In these larger pipes it is possible to enter and repair any lining that is damaged by the welding. A bell and spigot self-centering joint with an O-ring rubber gasket is gaining widespread acceptance as a joint for steel pipe in the West. It is more economical than the mechanical or welded type, and is easier to install. The *Victaulic* joint has been used in a number of instances but is ordinarily limited to pipe of the smaller sizes.

There are a number of combinations of linings and coatings available for steel pipe, but the most satisfactory have proven to be either of coal tar or cement-mortar. Hot coal tar pitch over a coal tar primer has been used for many years as a protective lining for steel pipe. It has proven satisfactory in many installations. However, difficulty has been encountered because of a lack of adhesion between the lining and the pipe wall. The author knows of several instances in which linings have completely come out of the pipe. To obtain a satisfactory coal tar lining installation, it is necessary that rigid controls be exercised over the lining materials and their applications to assure that adhesion is obtained between the lining and the pipe. After the lining is applied, special care must be taken to assure that the lining is not damaged in handling and is not subjected to cold temperatures. Coal tar enamel lined or coated pipe should not be exposed to temperatures below +10 F or handled when the temperature is below +20 F. Cement-mortar lining has gained general acceptance as a protection for the inside of steel pipe. It can be placed either in the shop or after the pipe line is installed. Again, care must be exercised to assure that shop applied cement-mortar lining is not damaged when handling the pipe. For this reason, most of the larger pipe lines are lined after installation in the trench.

The most commonly used exterior coating for steel pipe is a coal tar enamel over a coal tar primer with or without a felt wrapper which is usually of asbestos felt. For extraordinary soil conditions or submarine lines a fibrous glass mat is sometimes embedded in the coal tar enamel for additional protection. In recent years, especially in the West, a cement-mortar coating reinforced with steel mesh has gained general acceptance. Specifications for coal tar coatings and linings, and cement-mortar protective coatings are covered by standards.(12, 13) Shop fabricated cement-protected steel pressure-pipe is now obtainable under a standard Federal Specification.(14)

The principal advantage of steel pipe for use in water distribution systems is its inherent strength and ductility which allows it to maintain its integrity under movement and shock loads. Because it is a yielding material, steel pipe has more of a safety factor than does other pipe material when surge pressures occur. Although cement-protected steel pressure-pipe in smaller sizes is used in many systems in the West, it has not gained general acceptance in the Middle West or the East, except in large mains. It has not been generally accepted, primarily because it cannot be tapped as readily as cast iron pipe, and because of the proven experience record of some of the other materials.

CONCRETE PIPE

Concrete pipe is available in four basic types (1) reinforced concrete pipe with a steel cylinder, not prestressed,(15) (2) prestressed reinforced concrete pipe with a steel cylinder,(16) (3) reinforced concrete pipe without a cylinder, not prestressed,(17) and (4) prestressed reinforced concrete pipe without a cylinder. Although there are no standards available for the design of concrete pipe which considers the combined effect of external load and internal pressure, an empirical method has been published in the *AWWA Journal*.(18) This method can be used as a basis for design of prestressed concrete pressure pipe. When specifying concrete pressure pipe, the following information should be stated to serve as a basis for pipe design.

1. Internal working pressure (IWP)
2. Water hammer allowance (WHA)
3. External dead load, 3-edge bearing equivalent (EDL)
4. External live load, 3-edge bearing equivalent (ELL)

The author's firm requires that concrete pipe be designed to comply (after all shrinkage and plastic deformation has occurred) with the following:

1. The combined loading of (IWP) and (EDL) shall not be greater than 90 per cent of the incipient cracking strength of the pipe.
2. The combined loading of (IWP), (WHA), and (EDL) or (IWP), (EDL), and (ELL) shall not exceed the incipient cracking strength of the pipe by more than 10 per cent.
3. The combination of $2\frac{1}{2}$ times (IWP) and (WHA) and $1\frac{1}{2}$ times (EDL) or the combination of $2\frac{1}{2}$ times (IWP) and $1\frac{1}{2}$ times (EDL) and (ELL) shall not be greater than the ultimate strength of the pipe.

Tests are also required on representative specimens of each size and class of pipe to prove the design.

There are two basic joints commonly used with concrete pressure pipe. These are rubber and steel joints, and rubber and concrete joints. Both of these joints use an O-ring rubber gasket which is confined in a groove in the spigot, and which is compressed when the spigot is inserted into the bell.

Concrete pipe has gained general acceptance throughout the country for the larger sizes of mains used in water distribution systems. It is not so readily tapped as cast iron or asbestos-cement pipe, and for this and economic reasons, it is not generally used in sizes smaller than about 16 inches. It maintains high flow characteristics and, since it is reinforced with steel and can therefore be classified as a semirigid pipe, it has some of the characteristics of flexibility and ductility obtainable with steel.

SUMMARY

It might be well to summarize some of the practice and the factors which influence the use of certain material in various locations in the United States. These are:

1. Cast iron or asbestos-cement pipe is ordinarily used in the smaller sizes for distribution systems, although cement-protected steel pipe is generally used in certain cities in the West.

2. Cast iron pipe is the most generally accepted type for small sizes because of its long satisfactory experience record, and its ease of laying and tapping.

3. Cast iron pipe is not suitable for some locations where soil corrosion or electrolysis is detrimental to the use of unprotected metal pipe. In these locations asbestos-cement pipe may be used.

4. In many cities the present trend is not to use cast iron or asbestos-cement for the larger mains because of the brittleness of the materials and the consequent possibility of line breaks when subjected to soil movement, settlement, or shock loads. It is felt by many engineers that a flexible and ductile material should be used in large mains where a pipe failure can cause considerable water damage or interrupt service to a large number of customers.

5. Asbestos-cement pipe should not be used in tight soils which are subject to shrinkage with changes in moisture content. When used in these locations, the pipe should be completely embedded in granular material.

In closing, it should be stated that the choice of pipe material, the kind of joints, and the type of pipe lining and coating to be used for a particular installation can be determined only after making a complete analysis of all factors peculiar to the locality where the installation is to be made. After this analysis, the choice should be based upon sound engineering and judgment considerations. Although it can sometimes be shown by an analysis that it is more economical to choose a material with a shorter life than possibly another, this basis for selection of materials in water distribution systems is questionable; it is always difficult to replace defective mains when an area has become completely developed. For this reason, the author feels that whenever its possible, all materials incorporated in a water distribution system should be selected on the basis of providing reliable service for the long-time needs of the customers served.

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WATER MAIN LAYING

George T. Watson[1]

It appears that all concerned--design engineers, field engineers, municipal water superintendents, and most of all, contractors --have been prone to minimize the importance of careful and proper water main installation. This, I think, has come about because of the great strides the manufacturers of water mains have made in the last decade. We all think of these many new, and wonderful, inventions and innovations as being a substitute for good installation practices. They are not. With this in mind, I will attempt to bring you as many technical findings and experience lessons as I can.

I will deal in four basic products that are most generally used and familiar to me in our area: cast iron, asbestos-cement, steel, and prestressed concrete water pipe.

Generally, the pipe manufacturer transports the material to the job site by truck, or to a nearby railroad siding by rail. In the case of truck delivery, most loads arrive on the job well lashed down and properly blocked. However, careful inspection to determine if any damage occurred in shipment is extremely important. With rail shipment most loads arrive in very good condition, but since the contractor or municipality has to unload and truck to the job site, inspection is again most important. The normal short haul from rail site to job site leads to some rather dangerous and unsafe practices by the contractor in loading and blocking. Care must be taken to insure that no damage is done because of shifting loads, or over-stacking to save time.

Once the truck is on the job site there are many methods of unloading. Small-diameter cast iron pipe, I think, is the most abused. It certainly does not have to be handled with kid gloves, but the practice of dropping one pipe at a time to the ground, or on rubber tires as the truck moves forward is a dangerous one, both from the point of view of the men involved and the possible damage to the pipe itself. I would recommend a crane or endloader with either a cable sling or a lifting clamp to unload. A multiple sling can be made that will speed up unloading operations. In the case of asbestos-cement pipe, small diameters may be unloaded by hand or in bundles. It normally arrives in palletized bundles and is comparatively light. Large-diameter pipe (10-inch diameter and larger) is generally handled in the same manner (by sling or center clamp) or by center cable "choker." If a sling with hooks in either end of the pipe is used, great care must be taken to either pad or widen the hooks so that the ends of the pipe are not damaged. If the pipe is to be stored in a highly populated area, great care must be taken to prevent blocks made slippery by rain or frost from allowing the pipe to roll, possibly injuring children. It is most important, when stringing or storing the pipe, to guard against rain water runoff that may enter and carry in dirt and silt.

Of course, on every water job there are valves and hydrants to be transported and stored. The same basic rules of handling apply to these as to pipe, with a very few exceptions. Great care must be taken not to damage the valve, or hydrant stems, since these are usually bronze and will not take much punishment. The only other basic thing to watch is to be sure that all valves are partially opened and stored on their sides (i.e., gates vertical, in winter weather) to protect against cracking due to moisture collecting and freezing in the body of the valve.

Immediately before installation, each pipe should be swabbed or otherwise cleaned to insure removal of any foreign matter that might have gotten into the pipe. A practice which is becoming more common is to dip the swab in a hypochlorite solution to aid in the final disinfection. This is quite inexpensive and very effective.

Each spigot and bell or coupling, in the case of cement-asbestos pipe, should be thoroughly cleaned before the joint is assembled. A wire brush and rag will do the job very nicely. This again, is quite inexpensive. However, it is worth a great deal in

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terms of time and money spent looking for improperly assembled joints in the line, due to a little dirt or a pebble in the groove under a rubber. A careful visual inspection by trained men, to insure against cracked or otherwise defective pipe, is also a "must" at this stage of installation.

There are two basic types of machines used today in excavating for water main trenches. They are the backhoe and the trenching machine. Both have their advantages and disadvantages, depending on the type of soil encountered. If you are operating in a stiff dry clay, or other type of soil that will support itself in a vertical trench wall, a trenching machine has many advantages. From the installer's standpoint, the most important of all is its speed. There is no machine that will excavate a trench faster or more neatly. There is also no damage to trees, shrubs, etc., due to the swinging boom of a backhoe. Another advantage is the very finely ground backfill material which makes for better settlement, and a more dense and complete backfill job. In densely populated areas the ability to confine the trench width at the surface is a definite plus because of a minimum of surface restoration, whether it be street surface or grassed areas.

However, we don't always have these ideal soil conditions. In more unstable soils, shale or rock, we must then turn to the contractor's friend — that swinging, messy, rough, but reliable, backhoe. These machines are not always neat, but they are sure. Very versatile tools, backhoes are used in many ways on a water job. Some ways in which they help us are: unloading pipe, placing pipe and fittings, tree removal, building demolition, concrete breaking, frost breaking, excavating under existing utilities, and finally, often saving a man's life if the trench walls begin to cave in.

In a very broad classification manner we have five basic soil conditions with which to contend in water main installation. They are as follows: clay, loam, peat, granular material, and rock. Clay and loam give us the least trouble in excavation, due to the cohesive nature of the materials which make vertical or near vertical trench wall excavation possible. Peat is a very broad term which we give to almost any organic material of an unstable nature. This material is extremely difficult to deal with and often takes a lot of on-the-job experimentation to determine how much foundation material is necessary to support the pipe. We have used hardwood lumber laid crosswise, vertical piles, or heavy layers of 2- to 5-inch stone, all in an attempt to distribute the load enough to create proper bearing. If at all possible, I would recommend re-routing a proposed line around an area of this type, or excavating and replacing with granular material or clay, if the unstable material is not too deep. I say this because, even with every precaution possible, this type of base material still creates many construction and maintenance problems. As long as it is dry, granular material is ideal material. Vertical trench banks are rarely possible, but perfectly natural bedding is always available. Rock, if it is too hard to excavate economically by mechanical means, is a material to be dealt with by experts. Only well qualified explosive people should be allowed to "shoot" the rock. Once it is properly shattered, it can be handled by conventional methods. Great care must be taken, however, to make sure that the rock is removed below the bottom of the proposed pipe at least six inches. Granular material should then be filled in to make a proper uniform supporting base. If the shattered rock is used as backfill, granular material should also cover the pipe to a depth great enough to insure a proper cushioning effect when the backfill is placed. Water-bearing sand creates an interesting problem, but not one that is unsolvable. Well point systems have been perfected that allow the installation of water main in water-bearing sand, with no interference from the water itself. I would recommend consulting with one of the many firms that lease equipment, so that they can help analyze and solve your local problem. At this point we have discussed the five basic types of ground conditions encountered in our general area. However, we very often find ourselves faced with combinations of these, along with ground water. This is when on-the-job ingenuity comes into play. No one can give you the answer from here. You will have to be flexible and try different methods until one works. Then you should be prepared to change again as the ground conditions change, always keeping in mind that the proper installation methods for the pipe and fittings you are using must be maintained, because if the excavation and laying are difficult initially (because of bad soil) the repairing work due to faulty workmanship is even more so.

When vertical trench walls are possible, as a result of firm and cohesive soil, great care must be taken to insure the safety of the men installing the pipe. Seemingly firm material can be a death trap for a man stooping over to assemble a joint. There are aluminum collapsible trench jacks and supports on the market that can be slipped into the trench by one man. These can be expanded hydraulically in a matter of seconds, thus affording the man assembling the joint ample protection. These jacks and supports are not too costly. Very often the soil encountered will not stand vertically, and the trench must be cut in the shape of a "V" until the soil reaches its normal angle of repose. This method is fine where there is plenty of room and existing underground utilities are not endangered. Unfortunately (since much of our present-day installations are in old, built-up sections of communities) to re-enforce the existing system, we are faced with confining the width of our excavation, regardless of the soil conditions. This must be done with either skeleton sheeting, i.e., trench jacks and vertical boards, or a tightly sheeted trench. This, of course, increases the cost of the project and so must be taken into consideration when drawing the plans and specifications, and preparing cost estimates.

Since we have pretty well covered the various methods of excavation, let us move on to the handling and laying of the water main.

In sizes up through 8-inch cast iron pipe, the pipe may be lowered into the trench by two men using ropes. The most common method is to use two ¾-inch manila ropes, each piece being about twenty feet long, with a knot on one end, and the other smoothly bound. The men position the pipe at the edge of the trench and place the rope under the pipe about two feet from either end, with the knot on the ground some 3 or 4 feet behind the pipe, i.e., away from the trench. The unknotted end is then brought up and over the pipe so the men can hold it. Then, by standing on the knot and letting the rope pay out slowly through their hands, a smooth and rather simple lowering of the pipe is achieved. Because of its light weight and shorter length, asbestos-cement pipe can be handed to the men in the ditch. However, all pipe 10 inches and larger should be lowered into the trench by mechanical means. There are several pipe clamps available to hold the pipe while lowering it. Some people use a wire rope "choker" which is also very satisfactory. A crane or side boom tractor serves very well for lowering the pipe. If a backhoe is used for excavation, it serves very well to lower the pipe. The backhoe can also be used to position the pipe in its socket if one of the many compression joints are used. However, because of the danger to men in the trench and the loss of production by the hoe while it is being used to set the pipe I, personally, do not like to see a backhoe used for this purpose.

Very careful examination of both ends of the pipe should be made just before lowering the pipe into the trench to make sure that there is no damage to critical parts of the joint. If a crane is used to lower the pipe, the men in the ditch guide the pipe until it is centered, while the crane holds it just off the trench bottom. Then a coffing hoist attached to the last pipe (and to the one being lowered) can be used to force the two together, or the rings and glands can be put on if mechanical joint pipe is used. If a lead point is used, the packing should be driven into position while the crane holds the pipe.

At this point I would like to stress the importance of firm or complete bearing under the full length of the pipe. This applies to all of the types of pipe I have discussed. Water pipe is not designed to be a structural member and transmit uniform loads to points of support. Rather, it is designed to carry water at a given internal pressure and to resist a uniform load while being supported by uniform and complete bearing. If we, in installing these various types of pipe, don't constantly keep this in mind, we are not using the material as it was designed to be used. Also, we are handing some municipality or water company a never-ending headache, in the form of broken pipe or leaking parts. There are several ways to support the pipe properly. One way is to shape the trench bottom by hand so that the pipe is resting on a uniform undisturbed earth surface, and to hand tamp fine excavated material up to the spring line. Another way is to excavate a little deep and tamp fine excavated material for a foundation and up to the spring line. My favorite method is to excavate 3 or 4 inches too deep, and fill up the foundation with sand or other granular material (other than cinders) and then tamp the granular material up to the spring line. On smaller sized pipe the cost of this last method is incidental. However, on larger sizes the cost of foundation material rises as the pipe diameter increases. The initial cost of good bedding is, in my opinion, an extremely good investment in the future, because of many less breaks and, consequently, less maintenance cost.

We now have the pipe in the ground. However, fittings in the line to accommodate hydrants, valves, spur lines, etc., must certainly be considered. In order to accomplish the installation of such fittings, the pipe must be cut or fitted with openings to properly locate such fittings. When using asbestos-cement pipe, the manufacturer will normally include a certain percentage of random lengths. If the foreman plans his work carefully, combinations of these random lengths will often put the fitting where it belongs without cutting a pipe. If cutting of asbestos pipe is necessary, a convenient hand-operated tool is manufactured that accomplishes both cutting and milling of the newly cut ends to accommodate a coupling, adaptor, or fitting, as is necessary. In cast iron construction, the pipe is normally manufactured in either 18-foot or 20-foot lengths, using diameters up to and including 12 inches. A hand-operated pipe cutter (using a hydraulic pinching type cutter) is extremely fast and very effective. After cutting cast iron it will fit immediately into a mechanical or lead joint bell. When compression type joints are used, the freshly cut end must be beveled with a hand file or power grinder to accommodate the bell. Prestressed concrete or steel pipe is delivered on the job with side openings and fittings made at the proper point if accurate plans are given to the manufacturer prior to production.

Naturally, since our pipe line is to carry water under pressure, great thrust is developed at points of curvature, tees, or dead ends. We must resist this thrust in order to keep our line from pulling apart at these critical points. This is accomplished by reaction blocking at the point of greatest thrust. The most common methods of resisting such thrust are hardwood blocking, concrete, tie rods, or welded joints. In small-diameter cast iron or asbestos-cement installation, hardwood reaction blocking is satisfactory if the soil is very dense clay or rock. If the soil is anything less firm, I do not recommend this method because of the difficulty in getting enough bearing surface to properly resist the thrust. Concrete poured behind such fittings and curves, with very simple forming, is very satisfactory, but great care must be taken to leave the joints exposed for repair and inspection. Steel tie rods with the proper coating to protect from deterioration are a very effective means of resisting this thrust. They are not so expensive as one might think. These are most effective in vertical curves of small-diameter pipe. Welding joints together in steel and prestressed concrete pipe is also effective, but reaction blocking is, I think, a fine safety measure beyond this. Reaction blocking in large-diameter pipe is an engineering problem which should be very carefully designed and then adapted to field conditions. This becomes highly technical and much too involved to be covered at this time.

With the advent of the many new and improved joints on the market today, most water main is backfilled as it is laid. I still advocate backfill only between joints until hydrostatic testing is completed between valves. In highly congested areas this is sometimes difficult, if not impossible, and even greater care must be taken to insure good workmanship and material. Finding leaks in a newly constructed line in order to meet hydrostatic test specifications can be very time-consuming and costly. I, and any one of my fellow contractors, will attest to that.

The most common machine used to backfill is a bulldozer or endloader on crawlers. These do a fine job in an area that affords plenty of room. We must again consider the problems of congested areas. Here we very often must use a rubber-tired loader for backfilling and loading trucks. Another machine that has gone out of general use, but still serves a very useful purpose, is the old time "backfiller." This is nothing more than a dragline bucket. The obvious advantage here is to be able to pull the backfill towards the ditch rather than getting behind and pushing. This saves a great deal of restoration.

Where early and complete compaction is necessary there are several methods to use: mechanical tamping, puddling, or backfilling with granular material. If the excavated material breaks up easily, or is dug by a trenching machine, mechanical compaction is very effective if the layers of backfill do not exceed 4 to 8 inches. However, this is very expensive due to the high cost of labor to properly place and compact the backfill material. Flushing, or jetting (as it is sometimes called), is very effective if it is done very thoroughly through a pipe forced vertically downward at frequent intervals, and if enough water is introduced to thoroughly break up the backfill, thereby filling all the voids. This method is rather inconvenient in congested areas, although we have done it down the center of very busy streets quite successfully. The cost of this is much less than mechanical tamping, and we think equally, if not more, effective. Granular backfill is the quickest and very often the most economical method of achieving compacted backfill. If a street must be opened to traffic, or paved almost immediately after construction of the water main, this method (with some flooding to insure all the voids possible are filled) is unbeatable.

We are often faced with the problem of installing a water main under a busy highway or railroad. Here again there are several alternative construction methods: steel sleeves bored or jacked, concrete sleeves jacked in place, straight boring, tunnelling, and direct jacking. There are several boring machines manufactured which will bore a hole and jack a steel carrier sleeve through at the same time. This, I think, is the future universal method of making such crossings. Concrete pipe jacked into place, with miners cleaning out the front as it moves forward, is a fine and sure method. Here, great care must be used to construct the jacking pit in such a manner that the reaction blocking will resist the forces necessary to push the pipe forward. Through experience, we have found that a concrete backstop and a properly drained jacking pit are well worth the extra time spent to build them. If we encounter stiff soil we are sometimes able to bore a hole all the way and then thread the pipe through the hole. Direct mining, or tunnelling, is also a good method if stiff soil is encountered. With this method, and the concrete pipe jacking, sand can be placed very easily around the pipe to insure against settlement. The last method, direct jacking, has lost its popularity in recent years, but is certainly worth mentioning. With small-diameter pipe a hydraulic jack can be placed at the end of a pipe to force it through the earth. Then another pipe can be added. We have done a lot of this, but the percentage of failures is high. Most railroads will no longer allow it. In my opinion, the first two methods are the best, because if a leak develops under the road or railroad, the water follows the sleeve out beyond the traveled way and does not undermine the road bed. We have worked for several engineers who insist on a carrier pipe large enough to allow a man to enter, inspect, or repair a leak, through manholes constructed at either end of the carrier pipe.

Our pipe problems are now pretty well covered, so let us devote a few words to the so-called appurtenances, i.e., valves and hydrants. There are only a few simple rules involved here: (1) When a hydrant is set, be sure it is plumb. Nothing looks worse than a hydrant that resembles the leaning tower of Pisa. (2) Construct a firm base on undisturbed earth, or with a concrete base, to insure against settlement. (3) Last, but not least, make sure you have a good reaction block behind the hydrant, and enough gravel or stone around the base to insure good drainage when the hydrant is closed.

Valves should also be carefully plumbed so that easy access with a valve key is possible through a valve box. Also, be sure that the packing-gland nuts are tightened down, or leaks might possibly develop. In large valves where a vault is used, a concrete foundation should be poured under the body of the valve.

All of our good practices in installation are certainly necessary for a good usable distribution system. However, we must not forget safety for the men installing the system, and safety for the public. We feel that every man on a job of this type should wear a "hard hat." The ways that a man can have a head injury are certainly obvious if one thinks about the exposure inherent in this type of work. Also, trench jacks and boards to protect the man making the joints should be used. This is of utmost importance unless the earth is absolutely "fool proof" as far as any caving is concerned.

All of the public utilities are very willing to locate their underground systems for us if we will only call them in time. They are also very cooperative in regard to moving overhead cables, poles, etc. Slings, cables, chains, and machines should also have periodic inspection to insure against wear or damage that could take a man's life. When the job is left at night, make sure that all possible holes are filled, and that plenty of barricades and lights are used. We have found that what seems like ample protection is often not enough.

In summation, I feel that this phase of construction, like any other, is rather straight forward if a few basic principles are adhered to. With many future generations availing themselves of the service provided by a water main distribution system, we must see that they are not "sold short" by poor installation methods. The economics alone should be enough to provide us with the proper stimulus to provide as nearly a maintenance-free system as possible.

TAPPING, DISINFECTION, AND INSPECTION OF WATER MAINS

R. A. Wilford[1]

The topic which I have been asked to discuss, "Tapping, Disinfection, and Inspection of Water Distribution Systems," seems to me to be in the reverse order, so I have decided to present them in the following order: Inspection, Disinfection, and Tapping. I also believe this to be the proper order of importance, for without good inspection you have nothing that will hold water, and without water, no reason to disinfect or tap. This, of course, is a gross exaggeration but I want to emphasize the importance of good inspection. Without it you could be in for a lifetime of trouble.

The "degree" of inspection needed for any job depends on three factors: (1) the reliability of the contractor, (2) the experience or qualifications of the contractor, (3) the degree of difficulty of the job being done. When I say "reliability of the contractor" I mean his reputation for honesty and high standards of workmanship. It is usually a good idea to make a few inquiries of others who have had work done by the contractor. If he has a reputation of doing poor work then you had better plan on having a close inspection.

If the contractor has proven to be reliable then chances are that he is qualified to do your job. To be qualified he should have the equipment, tools, and the actual experience of doing similar jobs. If the project is a new experience for him, then close inspection will be needed.

The more difficult or intricate, the tighter the inspection should be. This is not only for your protection but also for the protection of the contractor. When working with close tolerances on large-diameter water mains a mistake of inches could cost the loss of expensive materials and valuable time.

In most instances of water main construction, close inspection is not necessary. Usually contractors hired to do this work are qualified and anxious to please. We have found, in our experience in Cedar Rapids, that there are some contractors who need little or no inspection, while others who have less scruples, need constant inspection. A contractor who has been in the business for long soon learns that it usually does not pay to cut corners. He will find that he will earn himself an unsavory reputation which will lose him work in the long run.

Inspection does not necessarily begin just when construction is started. The plans and specifications for any job are the laws which govern how a job shall be done. It is important that the specifications have adequate provisions for strong inspection so that the inspector can, if necessary, exert his authority and curtail any substandard work. The specifications should also write out any unqualified bidders. From personal experience I can tell you that this is very important. This past year we let a contract for installation of a 24-inch steel water main across the Cedar River to replace a 24-inch line that had failed last April, during the spring flood. Because of delays, we were unable to let the contract until late in the summer. There were five contractors who submitted bids. Of these five, four were reliable companies who had done similar work before. The other was a building contractor who had very limited experience in this type of work. Needless to say, the low bidder was the building contractor. His bid was $83,000, while the next low bid, which was only $975.00 more, was made by a highly qualified contractor who had done similar jobs before. The Water Department wanted to accept the bid of the more qualified contractor, but we were advised by our consulting engineer that if we did, it would cause considerable delay, for if the low bidder wished he could involve us in a lengthy legal battle trying to prove him unqualified. The low bidder, incidentally, was a large contractor who had no difficulty getting bonded for the job. We were pressed for time so we were forced to accept the low bid, and hope for the best.

It was the contractor's first experience with 24-inch steel water pipe which was coated with coal tar enamel inside and out. This, combined with the fact that it was also his first attempt at a river

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crossing, and a difficult one at that, meant trouble from the start. The completion date for the job was to have been November 1, but only yesterday did we flush the main in preparation for putting it in service. Three and one-half months late on a job that should have taken only six weeks!

An experience of this type points up the necessity of being sure that your specifications rule out the possibility of an inexperienced or unqualified contractor getting the job. Be explicit; spell out what is required of the bidder. We thought our specifications did, but we found out differently.

Having provided yourself with a strong inspection clause, and ruling out any unqualified bidders, the next thing you need is a good inspector. Often the mistake is made of having just anyone act as an inspector. I spent one summer working as an inspector for the Highway Commission. During that summer I was put on a bridge project as the inspector. At the time, I was a freshman in college and had no experience in that type of construction project or, for that matter, any type of construction project, outside of an occasional treehouse we built as kids — and some of those were a little shaky. Needless to say, I was of little value to the project.

Another instance of poor work due to inexperienced inspectors happened in Lake, Wisconsin, which is now a part of Milwaukee. Here, after a very high percentage of main leaks had developed over the years, an investigation was made. It was determined that "Improper trench conditions were caused by faulty inspection which permitted poor construction methods to be used." The inspectors on this job were college students who were attending a local university. I do not mean to imply that college students never make good inspectors, but rather that a bit of experience is a great help. With proper briefing a college student can do an excellent job of inspection.

Good inspection demands a good inspector. What are the qualifications that make a good inspector? The prime requisite, I believe, is that a man be experienced in the methods and materials being used to do the job. For normal water main installations this is usually no problem, because all water departments have men who have been around long enough to fill this requirement. Next, the inspector should be conscientious. He should take a real interest in what he is doing. Letting him know what an important job he is performing will tend to keep an inspector alert. He should be reliable to the point where he needs little supervision.

Another qualification which is most helpful in making an inspector well rounded, is the ability to be firm and to have an air of authority. Often, by merely standing around and *looking* as if he knows what is going on, the inspector can help to keep the contractor in line. It is not advisable to rely on this alone, however, for it does not take long to be found out. Accompanying an inspector's firmness, it is also important that he is fair and shows good judgment. In any work, some change in plans may be warranted which may benefit one or both parties. Although it is not the responsibility of the inspector to make changes, he should be open-minded enough to see where corrections could be made and to make recommendations to the engineer for study.

Now that we know what it takes to make a good inspector, what are his duties? The purpose of inspection is to be sure that you are getting what you have paid for. An inspector's duties begin with having a thorough knowledge of the plans and specifications. He should be briefed thoroughly on points where special emphasis is needed. If new methods or materials are being used he should become familiar with them. During actual construction he should keep close contact with how materials are handled and he should make frequent checks to be sure that faulty materials are not being used. Any questionable materials should be marked and set aside by the inspector. He should be sure that these materials are not reused.

The most important thing that an inspector must watch in laying water main is the bedding conditions for the pipe. More failures occur because of poor bedding than for any other single factor. Cast iron pipe is strong and durable but it is no good as a structural member. If the pipe is not fully supported for its full length it is acting as a beam supporting the overburden. The inspector should be sure that the entire length of pipe is supported and that no rocks or other objects rest against it.

Over the past 15 years, in Cedar Rapids, there have been 150 miles of new water main laid. The Water Department has installed approximately 100 miles of this, and the remainder was placed by contractors with little or no inspection. The number of leaks in the 50 miles laid by contract is approximately five times that of the main put in by the Water Department. The principal reason is simply the bedding conditions of the pipe. A contractor does not want to spend the time tamping dirt around the pipe in the ditch, and will, if not watched, just push the back fill in quickly with a machine. It is the job of the inspector to see that this does not happen.

An inspector should be told to keep a daily record and make notes of the happenings of each day. This record should include the number of feet of pipe laid, location of fittings, any changes made in plans, and other important happenings of the day. The record should be written up at the end of each day and be available to the engineer at all times.

One final duty of the inspector is to watch for violations of safety rules. He should keep on the alert for any possible situation which might lead to an accident and warn the contractor's supervisor of any impending danger, such as a ditch which could be close to collapsing, or a pipe sling which is worn or frayed. If the contractor fails to heed his warnings, the inspector should report this to the engineer; the engineer can then contact the contractor's insurance company, if necessary.

An inspector's duties are many, and his job is extremely important. The man chosen as inspector should be carefully selected and made aware of his importance. I have mentioned a few of the specific duties of an inspector, such as watching the bedding conditions of the pipe as it is installed. One other duty which is sometimes, but not always, under the jurisdiction of the inspector is the disinfection of new water mains.

The disinfection of newly laid water mains is no longer the problem that it once was. Years ago when jute or hemp braids (with their tendency to support growths of pathogenic organisms) were used extensively, sterilization of new mains was difficult. Within the last ten years, however, the water works profession has changed to the new rubber gasket pipe of the "O" ring, mechanical joint or slip joint type. There have also been improvements in the caulking materials used for the poured joints which have reduced the difficulty of disinfecting new mains. The City of Cedar Rapids had changed to the use of slip joint pipe prior to my arrival, and we have not used the poured type joints since I have been there. I think this is the principal reason we have had no problem with disinfection of our new mains. There has been no record of a "bad test" on any new water main installed since slip joint pipe was adopted as a standard in Cedar Rapids.

Complete disinfection of a new water main can be obtained if the following measures are taken during and after installation. (1) Keep the pipe reasonably clean while laying. (2) Cover the end of the pipe after each day so that no small animals can get in. (3) Allow plenty of openings so that a velocity of 2 to 3 f.p.s. can be obtained when flushing. (4) Use a chlorine dosage of at least 10 p.p.m. and allow a contact period of 24 hours. (5) Flush well before and after the contact period. (6) Test before turning into service.

It is important to get enough velocity to scour out any collected matter in the pipe. The mistake is often made, especially on large-diameter mains, of allowing too small an opening for flushing. It is not possible to flush a 12-inch main through a 2-inch blowoff, although I have seen it tried. Usually hydrants are located along the new main which can be used for flushing.

The methods used for addition of the chlorine dosage can be as follows: (1) Add a measured amount of hypochlorite solution at every few joints as the pipe is laid. (2) Feed chlorine gas into new sections as they are being filled. (3) Add a hypochlorite solution to the main as it is being filled. There are other possible methods but these three seem to be the most widely accepted. Of these methods probably the most widely used is that of putting a small amount of hypochlorite at every few joints. This also happens to be the least effective because as the water is fed into the new section it washes up and carries the hypochlorite along. Consequently, one ends up with a high dosage at the far end of the main and very little, if any, at the start. By feeding chloride gas or a hypochlorite solution as you fill the main it is possible to get an even distribution of chlorine residual throughout the pipe.

Unless the new main has been subjected to a high degree of contamination, a residual of 10 p.p.m. for a 24-hour period is usually sufficient. If, however, it has been in contact with highly polluted water, a higher residual from 50 to 100 p.p.m. is recommended. When using the higher residuals it is not advisable to allow the pipe to sit longer than 24 hours. Instances have been reported of damage to the pipe lining after several days contact with a very high residual.

To disinfect a new main there is usually plenty of time to do a thorough job. However, the disinfection of a broken main after repair is often neglected in the rush to get the main back into service. A few precautions taken during and after the repairs are made will help in keeping the main sterilized. These are: (1) Keep the water level in the ditch low enough so that it cannot run into the break. (2) While excavating, keep a slight amount of pressure in the broken pipe so that no foreign matter can enter through the break. (This is not always possible, especially in larger mains.) (3) Swab all repair parts with a strong solution of hypochlorite. (4) Flush the main thoroughly very soon after repairs are made.

When a leak is discovered it usually has been running for some time and has had a chance to saturate the soil around the break. When repairing the break an effort should be made to keep the seepage from the banks from getting back into the main. This can be accomplished by having a sump in the hole and a pump running to keep the water level down.

When excavating for a leak a small amount of pressure inside the main will help keep out any contaminated water. If the break is too large this is not practical, as the escaping water will cause considerable difficulty and hamper repairs.

By swabbing all repair parts with a solution of 100 p.p.m. of hypochlorite you will cut down the possibility of any contamination; however, this is not always 100 per cent effective.

It is important to flush the main as soon as repairs are made with as high a velocity as you can safely get. The flushing will usually stir up sediment already in the main so the flushing should continue until the water clears.

When a main breaks, especially a large main, there is always the possibility that somewhere in the system you will have negative pressures which will cause back siphonage or allow polluted water to find its way into the main.

Two years ago we had a 24-inch break which caused a great amount of back siphonage in one section of town. It broke about that time in the morning when everyone was just getting up, about 7:00 a.m. We were deluged with phone calls from irate customers who could only get air out of their faucets. What they were really getting when they turned on the faucet was the sucking noise of air entering the main. It took about 30 minutes to shut down the main, but in that time we had emptied several hot water tanks and pulled the system full of possibly polluted water.

We were scared, to say the least. Our first move was to hurry to the area, which had been under negative pressure, and flush every hydrant thoroughly to remove the air and as much of the water, that had been sucked back into the main, as possible. We then took samples at several locations for bacterial tests. Fortunately, we had no positive tests in all the samples taken. We were fortunate in that we had a residual of 0.5 p.p.m. of chlorine in this area which we carry as a standard procedure.

A distribution system can get contaminated in many ways such as back siphonage, cross connections, growths which pass through the purification process, and others. To combat this, it is always advisable to carry a chlorine residual of between 0.5 to 1.0 p.p.m. With a slight residual you cut down the possibility of any wide-spread contamination which might force you to disinfect your whole system.

Now, that we have the main inspected and disinfected we are ready to make a tap. Probably the earliest recorded tapping for water is found in the documents of Sextus Julius Fontinus, a commissioner of the Roman Water Works in the First Century A. D. In his day "tappers" were men who went out and operated gates to allow water to flow into various branches and ducts off the main aquaduct. Since then, tapping has advanced to the point where a man who makes a tap needs only to crawl into a hole in the ground and pull his heart out over a tapping machine.

Tapping water mains is a relatively simple operation, and the methods used for tapping have not changed a great deal for several decades. There have been many refinements in the tapping machines themselves and the addition of power drives, but for the most part the methods are still the same. The basic idea of making a tap is simply to thread a hole into a pressurized water main, then place a valve, called a corporation, in that hole. The object is to stay dry while you perform this task. This is not always possible, but in every trade there are a few tricks which you should know to help avoid any pitfalls.

Trick number one is, be sure you are on the water main before you start the tap. Strange as it may sound, it often happens that someone taps a sewer, gas, or oil line by mistake.

The usual procedure for making service taps is to place them at a point approximately 45 degrees off the top of the main and in the direction that the service line is run. It is also a good idea to be careful when tightening the corporation cock so that you do not get it too tight. It is possible to strip the threads, or the corporation could act as a wedge and put substantial stress on the pipe which might lead to a break.

It is important that the service tap not be too large for the main. If, for instance, you try to make a 1½-inch tap on a 4-inch main you will seriously affect the strength of that main. The largest size tap recommended for any pipe depends on the type of pipe and local standards. In Cedar Rapids, we make taps up to one inch on a 6-inch main and up to 1¼ inches on an 8-inch main. The largest tap we will make without going to a tapping sleeve and valve is 1½ inches.

Tapping is always a two-man job. Any time there is a man in a hole there should be a man on top to watch the banks and to hand down the tools. If you send a man out alone to make a tap in a hole which is over his head, with no one around, then you are gambling with that man's life.

Besides service taps there are the larger taps which use tapping sleeves and valves. These are used for larger service lines or for connecting branch lines off feeder mains. They come in practically any combination of sizes and are quite economical. The same precautions which pertain to the small service taps also apply to the tapping sleeves and valve, all that is, but the location. In their case, they should be placed off to the side of the main, or 90° down from the tap.

When using the tapping sleeve and valve you have a chance to get a close-up view of the inside of the main. When the slug is removed it should be inspected thoroughly and any unusual conditions noted. If the slugs are wanted they can be tagged and stored for future reference.

One point I want to include on the subject of tapping is the use of a power driver for making both large and small taps. In 1955 Cedar Rapids began to use an electric motor driven portable threading machine to power their tapping machine. A 1500 watt generator furnished the electrical power. The success of this operation has been gratifying. The two original threading machines, which were purchased in 1955, have made an estimated 7000 taps and are still being used. They both have been reconditioned at one time but their durability has been astonishing. We recently purchased a heavy-duty portable threading machine which is now used for the larger taps.

I would strongly recommend the use of this type of equipment for any water company which makes a large number of taps.

I believe I have run the entire gauntlet of tapping, disinfection, and inspection of water mains. I realize I have touched only the surface of these subjects but I hope I have conveyed the main thoughts to you. Inspection can make or break a job. Normally close inspection is not needed, but if it is, choose your inspector well.

In regards to disinfection of new water mains, the introduction of the new rubber gasket pipe has made disinfection much simpler than it once was. Even in the poured type joints new and better materials now available have eliminated a great deal of the hazards which once caused difficulty in disinfection of water mains.

The tapping of water mains has changed little over the years. The basic idea is still the same. The same pitfalls also are present and caution should be exercised to be sure trouble is avoided. With the labor-saving electric power drive, you can increase your productivity and in time will, I am sure, become as sold on them as I am.

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OBSERVING FIRE PROTECTION REQUIREMENTS IN FUTURE WATER SYSTEM DESIGN

A. H. GENT[1]

In this paper, I wish to discuss the fire protection aspects of several features of future water supply design and make some informal remarks pertaining to some of the detailed standards. Also the nature of our evaluation procedures will be presented briefly.

By using the basic elements of forecasting, namely, profiting by the mistakes of the past, taking advantage of knowledge of present resources and requirements, and applying these to the comprehensible future, your planning can be more than an educated guess. Only "basking complacently in the glorious reflections of the past" has already resulted in serious water deficiency situations involving restrictions of normal domestic and industrial uses. We, of course, are all familiar with the regional deficiencies in ground water supply and run off which caught numerous communities with short supply, but a great many of these situations resulted even when the source was satisfactory due definitely to the lack of forethought. The future *will not* take care of itself; it must be carefully thought out by all of us.

The Illinois Inspection Bureau, representing the fire insurance business, has a very tangible interest in the future of water supply operations. While we have never operated a waterworks, *that's your business*, nor designed a waterworks, *that's the consulting engineer's business*, we are constantly on the *rim* of such procedures, endeavoring to obtain your cooperation and interest in the fire problem. *Tangible, definitely,* because *our* interest affects your customers, just as much as water quantity and quality for use in their day-by-day living and operations. In this day and age, with increased prices the usual thing, the continued nominal cost of fire insurance, and the ability of an insured to obtain proper, full coverage, can only be assured through the maintenance of satisfactory preventive and protective facilities.

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Since the supply function, as in military operations, is considered the most important in this campaign against our common enemy, gentlemen, you are in the fire business up to your neck. The fire problem is definitely *yours* and, until the electronic, atomic, or other future scientific profession develops a push-button operation which will inhibit large-scale burning, your product will continue its almost universal fire use.

Because of the present lack of even a vague possibility of this scientific development for general fire operations as we know them, the Fire Department Instructors Conference, through its Exploratory Committee on the Application of Water, and the National Fire Protection Association are studying better techniques for water use. Frankly, these studies definitely show possibilities of conservation, since one phase involves the development of improved larger capacity water spray application techniques for very short durations as compared to the present method where materially longer durations of water application are the common thing.

Some use was made of this method in some of the recent Western brush fire disasters, where, even though water was mainly in short supply, a considerable number of homes were still saved. However, for major municipal operations, it is the general opinion that the present prescribed duration of fire demand must still be contemplated for a considerable time in the future.

In view of our appointed lot of being on the *rim* of the design and operating phases of your profession, I cannot set a specific blueprint for you to follow. However, I can present some observations which I have made in almost 25 years of being on this *rim* position in Illinois. These observations, I hope, will be helpful to you in future design problems. They are derived from experience in the small- to medium-sized municipalities within our territory.

Providing potable water in good quantity through service meters for domestic and industrial use is always the prime thought with waterworks people and normally provides the means for the improved design necessary to meet increased demands. The continued ability to sell all the water you can put through the meters is to your advantage, because a going concern must operate that way. If a product is going good in a mercantile establishment at a profitable price, the worst thing that can happen to that business is the termination of, or the restriction of, the supply of that product.

It is interesting to note recognition of this in your business as expressed by a very able water supply engineer who when commenting on the fast rising populations along the Lake Michigan shore area stated: "First, improvements in quality were the problems of serving water. Now, quantity is the problem on hand to be carried out." You are in a boom business; getting it while it is here and paving the way for more is to your advantage. The customers want it — get mad if they can't have it — so get set up to sell it, with continuity of service assured even during periods of maximum demand.

I do not mean to imply that we should be wasteful with this very valuable product. Every means at our disposal should be taken to eliminate unwarranted misuse. Water waste through service and main leakage, unauthorized use of fire hydrants, and other unmetered connections should be and can be closely checked. Sprinkling controls, which discourage unnecessary severe waste, but still permit the maintenance and retention of the grass and foliage so necessary to the beauty of our homes and outdoor recreational facilities, should be given further study. Recirculation of cooling water or other means of reclaiming such supplies appear to be necessary in plans for the future. Following these and other steps toward conservation, sell all you can.

This demand must come off the top of the barrel. What is left is the fire protection reserve to provide the volume and the pressure required for public fire protection and to supply private protection facilities such as automatic sprinklers and standpipe systems. With per capita use at an all-time high and maximum hourly rates for domestic and industrial use sky rocketing, it is easy to see that to conserve the bottom of the barrel for fire safety requires definite forethought. Robbing the major portion of the bottom to take care of the top is surely not good design.

This fire reserve should be sufficient to meet the fire service requirements prescribed by the National Board of Fire Underwriters. These have always been considered liberal by waterworks authorities, but actual experience with major fire operations even in smaller communities indicates that they are pretty close to correct. In fact, even heavier demands in small- to medium-sized cities have been experienced because of the ever increasing availability of multiple fire pumper company response through our present widespread fire department mutual aid programs.

While it is our experience that smaller communities find it difficult to accomplish, since this fire demand represents a large percentage of the total, varying from about 80 per cent or more in cities under 5,000 to about 60 per cent in cities of 25,000 population, compliance with these requirements to the greatest degree possible is definitely urged.

These fire service requirements are contained in the *Standard Grading Schedule* of the National Board. The 1956 Edition is presently applicable, but this publication is constantly under study for revision to meet modern situations. This publication should be in the library of all men engaged in water supply operation and design. Its requirements should be a part of every modern waterworks man's knowledge.

Since these standards require delivery of maximum domestic, industrial, and fire demand, both with every portion of the system functioning and also with disruption of a reasonable number of components, so as to assure proper continuity of service, it may be seen that design along these lines readily lends itself to meeting unexpected increases in service requirements which are so common in our modern world. It has been our experience that systems designed and expanded in accordance with these standards are materially less susceptible to the necessity for restriction in service and emergency operations to meet these unexpected loads.

At times these reliability requirements, such as meeting maximum fire and domestic demands with an intake, purification unit, two wells or well pumps, two high or low lift pumps, a storage facility, a supply main, a power facility, etc., out of service, have been criticized as severe, but experience indicates that failures *have* occurred and such characteristics have definitely proven of value under expanding loads.

Furthermore, with the requirements for an adequate looped arterial system met, and other recommended distribution system features provided, an excellent basis for expansion exists.

In guiding design for water quality and source development, the various State Departments concerned with such matters do a tremendous job and their wealth of data will continue to be a basis on which these features will grow and improve. It has been interesting to note recent trends in Illinois toward the use of more than one of the major types of supplies common to this state; namely, wells, natural waterways and lakes, and artificial or impounded reservoirs. This may be the answer to protecting against periodic regional deficiencies in runoff and ground water, which have so greatly affected our sources in recent years. For instance, cities with impounded supplies have supplemented these with supplies from our major rivers or from wells, where ground water was also available. Also, cities with well sources have supplemented these with natural or impounded surface water or are considering such action. The use of multiple outlying well stations, discharging directly, and in some cases with individual treatment facilities, has also been of value to many cities in making best use of the ground water available and can be helpful in partially caring for localized deficiencies in distribution characteristics.

The changing character of our communities is a factor in our future considerations. Due to the automotive transportation system, with necessary road and highway projects, the public's desire for suburban living, the dispersion of industry and educational construction policies, major industrial, mercantile, and educational facilities are rapidly moving to outlying areas which historically have been considered areas of low water demand. Our past in many cases is catching up with us now, since few systems were designed with this possibility in view. The few that were, are indeed fortunate, and are cashing in industrially on this foresight.

For those communities which have industrial ambitions (and due to the curtailment of use of historically important natural resources usual to certain regions of our state, many now do) this problem of serving outlying areas becomes foremost.

Industry must have adequate and reliable water for industrial, sanitary and fire protection uses, and they want it from you. If they can not get it from you, they go elsewhere, because, regardless of the present inflationary trend, they are still economy-minded and know that development of private facilities is expensive. In the earlier days of decentralization, right after World War II, they took the glowing publicity of local authorities as gospel. However, many times following construction they were confronted with a sad situation. Now they look before they leap, and you better have it for them when they investigate, or you lose them. They are not taken in twice.

The automatic sprinkler system is the protective device mainly used by industry to assure continuity of operation of all portions of its production facility and to reduce insurance costs to a minimum. Remember how Oldsmobile production and sales suffered after the destruction of their unsprinklered automatic transmission plant at Livonia, Michigan, and you can understand why they desire such systems. An adequate and reliable public water supply system is considered the best source of supply for this facility, and industry is constantly looking for locations where such a supply can be made available.

These systems have an enviable record. Data kept for more than 50 years show that they have proven to be over 96 per cent efficient. This efficiency factor is based on fire control with a small number of heads operating. The opening of a large number of sprinklers in a fire area definitely smacks of failure and is so recorded.

Due to this ability, I would think that water authorities would *encourage* these installations. Fire authorities *do*, and these systems are commonly referred to as the "Fireman's best friend." Frankly, if you are looking for *conservation*, here it is in a nutshell. Think back on the major fires you have experienced in unsprinklered properties where millions of gallons of water were used over long periods of time to establish control. Compare this with the comparatively low flow occasioned by the automatic opening of not over ten sprinklers at about 20 GPM each to establish control. The device furnishes both automatic alarm and fire control service. It can be *your* best friend. Major fires occur mainly during periods when premises are unattended and the alarm is delayed. As a sentinel, it has an excellent record.

Once it is installed and a satisfactory water supply connected, various factors must be watched as your water service problem changes so that the future efficiency of sprinkler systems will not be impaired. Among these factors are changes in operating personnel, practices, and procedures, maintenance operations, changes in the location of elevated tanks and pumping stations, changes in consumption of a city as a whole, and in the local area under consideration, deterioration of pipe capacity because of tuberculation, closed gate valves, deterioration of supplies or reduction in capacity of pumps being depended upon, etc. Consideration of these in continuing a system's efficiency is a must.

How it is possible to guide any design for the *future* without adequate operating data and records pertaining to the *past* and *present* is difficult to understand. Furthermore, how efficient operation is possible without these is also hard to visualize. Detailed plans and records of operation, source, supply works, distribution, and services in accordance with the recommendations of A.W.W.A. is *not* an extravagance, it is as much a necessity as it is for any going corporation. Instrumentation should be complete, and by that I do not mean for the supply works only, but also for the distribution system. Remote recording elevated tank and reservoir level instruments and recording pressure gages in various areas of the system are vital in determining where re-enforcement must be accomplished in view of growing demands.

With the supply works designed to meet, and to be expanded to meet, the maximum expected 24-hour domestic and industrial demand with necessary duplication provided to assure continuity of service, it appears reasonable to depend on treated water storage (either elevated or surface with pumps) to contribute to a large degree to the maximum hourly and fire demand requirements. Lack of maintenance of source and purification facilities at the top efficiency necessary to produce maximum allowable rates of flow can definitely contribute to plant inability. Only where raw water is considered satisfactory for direct use, is treatment plant bypassing, to add to ability to provide fire demand, recommended. Where surface storage is provided in conjunction with the supply works, high lift pumping capacity and supply main capacity should be ample to produce, even with some disruption of service, a rate of flow at least equivalent to the rate of flow of the effluent of the purification plant or low lift pumping equipment, *plus* a rate of flow equal to the surface storage capacity divided by the required fire flow duration period. Otherwise, a water plant's ability to serve fire flow demand will be limited.

In selecting the size of storage, maximum hourly demand must be contemplated, so that during such periods a fire reserve will be retained. Where supply works facilities are less than the maximum expected 24-hour demand, and experience indicates that days of this type can occur in succession, continued dependence on storage to furnish maximum hourly rates will eliminate its value both for fire and day by day consumption purposes. This is also true where the main capacity serving a local area in which a storage facility is located is less than the 24-hour maximum use in that area. Frankly, you cannot take products from a warehouse continuously without adequate production or the warehouse will go empty.

Distribution system storage is exceedingly valuable to provide maximum local short duration demand and thereby reduce arterial system pipe sizes, but general system ability to maintain this storage is of prime importance. Outlying well, pump, and treatment facilities at these storage locations have been used for their proper maintenance. But even when these are provided, the availability of sufficient arterial main facilities to high-value areas is necessary to utilize storage to support fire demand in those districts which require high short-duration rates for fire flow.

Where large standpipes are installed and there is little ground elevation advantage, the provision of pumps to utilize the lower portion of the standpipe capacity, at good pressure, is recommended.

For general distribution system design, may I refer you to a very excellent paper by Mr. George W. Booth, appearing in the *Journal of the American Water Works Association*, Volume 36, No. 9, September, 1944. Mr. Booth describes in a very complete manner the arrangement and pipe sizes necessary to give practical service ability for both present and future demands. The future arterial system should be *so* planned and distributors should be capable of taking care of local service and also add somewhat to transmission ability. In industrial, mercantile, or institutional areas, the use of a liberal amount of 8-inch pipe for distribution served by looped arteries of larger size is highly recommended.

Mr. Booth had this to say about 4-inch pipe: "In an effort to fix upon economic pipe sizes in design, there is the temptation to use a much too great proportion of 4-inch pipe, which with the passage of time and the consequent falling off in carrying capacity becomes altogether inadequate for the demands made upon it, even in ordinary residential sections. That tendency to use 4-inch pipe is much less common than formerly, and the great majority of systems employ 6-inch pipe as the minimum size." I wish this tendency were true in our smaller communities in Illinois. Frankly, for complete fire and domestic services, 4-inch pipe should have no place in our future picture.

In any consideration of future design, we have no right to contemplate additions unless we get our existing distribution facilities in proper shape for expansion. Valve surveys to eliminate closed or inoperative valves, the provision of adequate size cross connections between arteries and distribution pipe, the cleaning of pipe to reduce tuberculation and the adoption of treatment to minimize its future collection, the elimination of air pockets at high points, etc., should be undertaken. Make sure your existing system is at its peak. Valve spacing should be investigated so that continuity of service on arteries and distributors will be assured and no great area will be denied supply because of a major break.

Provision of fire safe pumping stations, purification plants, and waterworks buildings are as vital to you as they are to industry. Fire resistive construction and the arrangement of all facilities in a fire safe way is the only way for the future.

The reliability of power supply for pumping, purification, and general operation cannot be overly stressed. Total elimination of service has occurred too many times in the past due to lack of proper duplication to overlook this feature. Electric service should be underground, and duplicated with transformer, control and sectionalized switchboard facilities properly arranged. Otherwise, a secondary source of power, such as internal combustion engine, is a necessity.

The fire hydrant is the outlet provided for the use of the fire reserve by the fire fighting forces. The future installation of fire hydrants meeting A.W.W.A. requirements with liberal flow characteristics at low friction loss, and at least 6-inch connections to distribution mains is urged. The replacement of fire hydrants having tortuous design and poor repair ability is a program which will further our joint interests. Auxiliary gate valves, preferably on all hydrant connections, and at least on those connected to arteries, will improve continuity of service especially in view of modern traffic and the susceptibility of the fire hydrant to automotive injury.

Close fire hydrant spacing along streets in our high-value industrial, mercantile, and public building districts in accordance with the underwriters' requirements is normally recognized as necessary by water authorities in view of the fire fighting problem presented. It is generally recognized that the multiple fire pumper company response, at times including mutual aid companies, requires numerous connection points close to the property to be protected to deliver the desired fire flow through short hose lines. However, with the modern tendency for large parcels of ground beyond street fronts, the rear of these properties ordinarily require additional consideration. Where hydrants are placed for this rear service, care should be taken that they are located on all-weather roads and accessible for the connection of fire department pumper suctions.

In single-family, large-lot residential areas, there has been some tendency to extend hydrant spacing to 1,000 feet or more on streets, with the thought that with modern small stream fog fire fighting methods, smaller ultimate fire flows will be necessary, and two 500 foot lines of 2½-inch hose will be the maximum required to serve the nozzle equipment used in fire fighting. This spacing, of course, is materially wider than the present ultimate recommended practice of about 350 to 400 feet. My only comment on this is that the fire fighting methods quoted as justifying this wider spacing are not as yet fully developed nor universally adopted and are not 100 per cent infallible. Also, some adaptations, which involve serving the suction of a fire pumper located at a piece of property through lines of 2½-inch hose stretched directly from the fire hydrant ports, definitely require the closer spacing now used as a standard. This latter residential fire fighting method, using very short hose lines of 1½-inch size, preconnected to the pump, is gaining widespread favor due to the speed in getting water on the fire, using the water tank on the truck as the primary supply, and, if needed later, supporting this mobile supply by 2½-inch hose lines extending to the pumper suction direct from hydrants.

In any event, this wider spacing does not lend itself to reliability, since inoperative or frozen hydrants can readily place the remaining hydrants outside proper hose line distances.

In these days of Master Community Plans for every purpose, along with zoning activities, for both municipalities and unincorporated county areas, it would seem to me that with these as a guide, water authorities could readily "blueprint," at least to some degree, their plans for the future. We, of course, all know that "change" is a constant thing and this "blueprint" would have to be altered periodically to fit situations as they occur, but I do believe a basic master plan for water system growth has some advantages.

From my experience, it appears that it would be a tremendous advantage for water officials to make improvements to meet expansion and need for more adequate service on a continuing basis, year by year, following this "master blueprint." Profits from the water supply operation could be used to accomplish these improvements, and believe me, I cannot see why any water supply operation should fail to make a profit under present conditions of demand. This, as compared to "growing like Topsy," or making a large basically inadequate improvement at one specific time, so as to cover partially as many trouble spots as possible with the money available, makes some sense to me. The consulting engineering profession has done and can do an excellent job along these lines. Frankly, this line of thought is not new and at some places has been tried and is serving a valuable purpose in this period of expansion. I am surprised that more communities have not availed themselves of this approach to the problem.

Where extensions are placed in newly developed areas, the operation is usually on the basis that the cost of these extensions shall not be borne by the whole tax area, but by the new users in the area being developed. As a result, design and installation of these extensions by subdividers and developers is not uncommon. If these installations are uncontrolled and unsupervised as to adequacy of design, the capabilities of your system can deteriorate rapidly. Furthermore, it is an injustice to the taxpayers using the existing system, if an installation, below the standards which they originally paid for, is permitted.

Water officials should, therefore, have available definite regulations and design standards for these extensions which must be met before permission is granted for service. These should cover service connection facilities, pipe, valves, hydrants, depth of cover, installation practice, pipe sizes, continuity of arterial feeders, etc. Plans should be approved before installation is started. Without such supervision you can end up on the short end of the stick.

There is also definite activity these days in the field of completely new water systems both for the older smaller villages of less than 1,000 population, which in the modern age desire these sanitary advantages, and also for new communities segregated from existing public or private systems. We are often asked for our requirements covering the fire protection aspect of these systems.

In view of the characteristics of the older villages and the funds usually available for the initial installation, we normally quote specifications based on the minimum which would be recognized for fire insurance rating purposes. This would include ability to develop at least 500 GPM from supply and storage for a one-hour period in addition to maximum consumption through all portions of the system. We, of course, recommend design with some thought for later expansion.

In rapidly developing communities, we, of course, urge initial design on a materially more liberal basis, especially where industrial, shopping center, and educational facilities are a part of the overall plan. Under such conditions, a fire reserve of not less than 1,000 GPM for at least four hours duration would be recommended. In addition, thought toward later supply works and distribution system expansion is urged.

In Illinois, the Cook County and Illinois inspection bureaus and the National Board of Fire Underwriters are engaged in the grading and evaluation of public and private water supply systems to determine their fire protective ability. The inspection bureaus inspect communities, structures, and facilities for the purpose of establishing fire insurance rates and report to their subscribing companies on the fire underwriting risks involved. The National Board of Fire Underwriters inspects and evaluates the public fire defenses of communities of over 25,000 population, and the results of such work are used by the bureaus in their rating and reporting procedures.

A number rating is applied to the public fire defenses of each community by these bureaus, which is determined by an intensive inspection and grading of the fire facilities. A major factor in determining this public fire defense rating is the ability of the water system to furnish the normal industrial, commercial, and domestic needs of the

Table 1

Relative Values of Factors Used to Establish the Fire Defense Rating of Illinois Communities

Factors Considered	Per Cent
Water Supply	34
Fire Department	30
Fire Alarm	11
Police	1
Building Laws	4
Fire Prevention	6
Structural Conditions	14
	100

Table 2

Fire Defense Ratings Applied to Illinois Communities by the Inspection Bureaus

Population Class	Number of Communities in Each Fire Defense Rating Category									
	1	2	3	4	5	6	7	8	9	10
2,500 and under					3	28	154	278	244	392
2,500–10,000				1	13	47	89	25		
10,000–25,000				2	10	20	10	4		
25,000–50,000				4	4	5	1			
50,000 and above			4	2	6					
Total			4	9	36	100	254	307	244	392

community and, in addition, to maintain a satisfactory reserve for fire protection. The number rating of the public fire defenses determines the base rate applied to specific residential, public, commercial, and manufacturing buildings in a specific locality.

Table 1 shows relative values of factors used to establish the fire defense rating of Illinois communities. The city classification derived by considering these factors is used to establish a fire insurance base rate for an individual property.

The classifications resulting from this evaluation vary from Class "1" to Class "10" inclusive, Class "1" being the best or indicating complete compliance with standards and Class "10" being the poorest (see Table 2). Communities with no water system or with a water system not meeting minimum recognizable fire protection standards are rated in the "9" or "10" categories.

The range involved is indicated by the following example: The fire insurance rate for a one-family, approved roof, brick residence in a community which has little or no town fire protection and has a fire defense rating of 10th class is about 260 per cent that of the same home in a city such as Peoria which has a 4th class fire defense rating. This 10th class dwelling rate is about 220 per cent of that in a 6th class community, 180 per cent of that in an 8th class community, and 120 per cent of that in a 9th class community.

The survey of the water supply system includes a detailed analysis of numerous items, including (1) consumption and operation records; (2) supply works including source, pumping equipment, etc.; (3) the size, arrangement, and condition of mains, hydrants, and valves; and (4) fire flow tests at hydrants in various locations in the community.

The mayor, city manager, and other officials of each community surveyed are informed of the results of the survey, including a summary of the major deficiencies of the water system and what action is needed to correct them. When properly authorized by the public officials, copies of reports and correspondence outlining corrective measures needed in each community will be sent to other responsible individuals upon request.

Full information pertaining to the services provided by the bureaus may be obtained for Cook County from the Cook County Inspection Bureau, 175 West Jackson Boulevard, Chicago 4. For Illinois outside of Cook County, the nearest of these Illinois Inspection Bureau offices should be contacted: 175 West Jackson Boulevard, Chicago 4; Gas-Electric Building, Rockford; 3100 N. Knoxville Avenue, Peoria; 12 West Lincoln Street, Belleville; Myers Building, Springfield.

MAINTENANCE OF WATER DISTRIBUTION SYSTEMS

J. M. Rogeven[1]

INTRODUCTION

The maintenance of a water distribution system, like the maintenance of your home, your automobile, or your cottage at the lake, is a never ending job. And unless the maintenance is done systematically and properly, your problems will pyramid to the point of obsolescence of your facility; this is poor economy and can and must be avoided.

The time and space allotted to cover this vast subject is not sufficient to delve into every detail and besides it would make this paper too long and quite unwieldy. For these reasons I shall attempt to cover some of the more important aspects as I have experienced them in this rewarding endeavor of maintenance of a water distribution system.

It would, no doubt, be well at this point to recognize the fact that many water departments do not have sufficient operating cash to do the work that they would like to do; or in some cases, to do the work that should be done to keep the system together. What we are concerned with here is what should be done.

WATER MAINS

For all intents and purposes, the maintenance of a distribution system starts with the water mains leaving the water pumping station, though technically some of our maintenance problems start with the water itself.

The distribution system or parts of it from time to time are turned over to you for maintenance. Up to this point you may or may not have seen the engineers' plans and specifications and you may or may not have watched the contractor install the mains. However, when it is turned over to you, it is your responsibility from then on. Theoretically it will last a hundred years or more; however, it seems it never fails that as soon as the guarantee period is over, your troubles begin.

Since we have the system to maintain, let us consider the problems with which we will be confronted.

MAIN BREAKS

Main breaks are caused by several factors, such as water temperature change, ground movement, freezing, improper backfilling, poor and improper bedding of the pipe, excessive loading, water hammer, excessive water pressures as well as faulty pipe, and other factors. All but two of these causes are a result of "human error" and could be avoided. These two are water temperature and ground movement. We can do little to avoid either of these. The others are a matter of engineering, design, and workmanship.

The breaks caused by these elements are of four different types: the transverse, the longitudinal, the "blow out" type, and the break caused by a fitting blowing off. Of these, the transverse (right angle to centerline of pipe) break is the easiest to repair with any one of several makes of permanent repair sleeves. These sleeves or clamps are available in one, two, or three pieces and in lengths of from six inches to thirty inches and for pipe sizes ranging from one inch to 24 inches in diameter and larger on special order. The longitudinal break, or "split" pipe as some refer to it, is simple to repair if you have a sleeve long enough to allow one-half pipe diameter beyond the end of the split. Our experience has taught us to remove this length of pipe and to sleeve in a new length. We have found that this type of break cannot be permanently repaired with a repair sleeve or clamp. Likewise, a pipe from which a piece has "blown out," we feel will also continue to give us trouble, so we remove it.

Let us consider a typical water main break. The repair can be made only after the water main has been isolated, a proper hole excavated, and the ditch dewatered — provided you have the opening in the right location.

We feel that it is good public relations to expedite the repair of a water main as quickly and

[1] Superintendent of Water Department, Jackson, Michigan.

quietly as possible. Why quietly? Most of our breaks are at night and any unnecessary shouting and boisterous talk by construction crews is not appreciated by customers. The power-driven equipment on the job is enough background noise for such a scene.

We have learned from experience that the break in a water main is not always right under the spot where the water shows up on the surface. This is particularly true on hard surfaced streets and on streets with other underground conduits such as sewers, electrical ducts, telephone ducts, gas, pneumatic tubes, steam heating lines, and oil pipelines. Any one of the trench lines in which these facilities lie can deter the water from rising straight up to the surface of the ground. To beat this situation, a jack-bit or auger is used to drill a series of holes directly above and along the water main to a depth of approximately four feet. This is done until a hole is drilled which, by its flow of water, indicates to us that we are over the break. Other breaks are less difficult to locate since the street is all washed away, the pavement down in the bottom of the hole, and the sidewalk just hanging on the curb boxes. We sometimes have breaks that flow into a sewer and would not be detected unless a sewer cleaning crew reported it — or the street caved in.

While the crews are preparing to isolate the broken main, attempts are made to notify all of our customers in the affected area of the need for turning off the water main to make the necessary repairs. We also attempt to inform them of the estimated length of time necessary to complete the job.

After these preliminaries are completed, your men are ready to turn off the last valve which will "kill" the pressure on the water main — you hope. Then you can start cutting the pavement, digging down to the water main, and pumping out the water and mud so that repairs can be made.

We should not leave this subject without mentioning the importance of turning off water services in some cases prior to shutting off the water main. I am speaking here of the services into homes or buildings from which you may possibly draw or syphon the water out of a boiler or tank. You could drain the entire system and cause considerable damage to the customer's equipment, particularly boilers, in spite of plumbing code requirements.

Whenever any repairs are made to a water main the trench must be kept as free as possible from flooding to prevent contaminating the water main. The pipe, to which the repair clamps or sleeves are to be attached, must be thoroughly cleaned to assure a smooth surface for the gaskets to seal against. With some types of repair clamps (those having thick or heavy gaskets) small amounts of a mild soapy water spread over the gasket will aid in the gasket's seating and sealing.

If flooding of the ditch continues during the repair operations, it is necessary to disinfect the water main before returning it to service. This is accomplished by the addition of a disinfecting agent, such as a hypochlorite. This chemical can be put into the water main by hand through the opening or by a pump injection through a corporation cock. This should be followed by voluminous flushing and coliform tests.

When the water pressure is on, and the main is returned to full service, and you find that the repair does not leak, the trench can then be backfilled.

Backfilling is another operation that is too often done poorly. Poor backfilling results in continuous maintenance for the street repair crews and in some cases causes another water main break. With only a few exceptions, the earth removed from a trench at a water main break is unfit to be used as backfill. This dirt should be loaded on a truck and dumped elsewhere. In some cases this material may be usable after it has dried. When backfilling (as we are considering now) sand and/or bank run gravel, well compacted from bottom to top, is a must for trouble-free roadway cuts.

I must not leave this subject without urging you to make positively sure that all of the valves that were operated are open and that the ones that were broken during this operation are scheduled for immediate repair. I said immediate because if it is not done immediately you may find that you will have another occasion to use this valve before it is repaired. If this does happen, you will have additional valves to operate and unnecessarily so. You will also have more customers out of water.

FROZEN WATER MAINS

Frozen water mains should never happen. However, they do and we are "stuck" with it. The reason for the freezing, of course, is insufficient cover over the main. This condition should not happen if the job is properly engineered. By engineered. I include taking into consideration any future changes in street grade, either cuts or fills. If the street grade is cut and the water main does not have sufficient cover — don't kid yourself — you had better lower it to protect it from freezing and from external loads.

We have found live steam to be the most effective means of thawing out a water main. We excavate near the frozen area, make a $1\frac{1}{2}$-inch tap and run a $\frac{1}{2}$-inch steam hose into the main, first in one direction, then in the other. If we do not have enough hose, we make another excavation, tap, and run the steam line in again. The operation is repeated until the water flows from one side. Then the side where water is flowing is valved off and the opposite side is thawed in the same manner.

We use electric thawing on services but have had no success with electric thawing on water mains. Perhaps we are too impatient. We have had very good success in burning up TV sets when thawing services when we did *not* remove the meter and ground wire jumper.

RECORDS

Records are among the most important tools of a water department. They consist of a complete set of maps, drawn to a scale of not more than 100 feet to the inch, that show the entire distribution system in the following detail: exact location of all valves with respect to property lines and/or section or $\frac{1}{4}$ posts; piping arrangement at intersections; type of structure (such as manholes, valve boxes, pits, casing or tunnel above or below ground); the depth of bury or cover over the main; the material the main is made of (cast iron, cement asbestos, steel, concrete, etc.); the class and size of pipe; the direction and number of turns for each valve; the location of the fire hydrants and the valve on the hydrant lead; location of valves on services four inches and larger.

For these records to be of any use to your crews they must be available on the job. Section maps, cards, or records are no good locked up in the safe in the office. At least the foreman should have a set available to him at all times, unless you have someone in the office 24 hours each day who can give you the information over the radio or telephone.

Detail records of your distribution system will save many hours of labor in the location of facilities on each job.

LEAKS

Leaks, large or small, are our most expensive and difficult maintenance jobs. Some leaks, like some main breaks mentioned above, go unnoticed indefinitely or until someone accidentally runs across them. Others show up on the surface of the ground sooner or later. Or, in some cases, the low percentage of accounted for water starts someone on a leak survey in which leaks from 25 gallons per day to 60,000 gallons per day or more are discovered. These leaks may come from any joint, connection, or fitting in the distribution system. They may be on a main, a hydrant, or a service line. If the leak has been detected by a leak survey and does not show on the surface, it may be located with a leak detector. If the leak shows up on the surface, it may be directly below the wetted area or it may be fifty yards or more away. Leaks showing on the surface of the pavement or at curb lines can be, and usually are, deceptive. You will generally find that the leak is someplace other than where you would expect to find it. This type of situation is caused by dense or rocky soil conditions, improper backfilling of trenches, or by several layers of impervious surfaces on the roadway.

There are several manufacturers of leak clamps for all of the different types of pipe joints, including a clamp which covers the entire bell. One of the problems in the past has been that of having a repair clamp, or sleeve, on hand that would fit the class of pipe being repaired. If you were fortunate enough to have repairs for all classes of pipe, then you had the problem of teaching the crews *which* repair clamp would fit *which* pipe. Then, when you got that across to them someone, in the meantime, had mixed up the gaskets or the bolts. Perhaps this would not happen to a well-organized water department — and if it did, it probably wouldn't get to the manager or superintendent anyhow. In any event, the manufacturers recognized the problem and now make one repair sleeve and clamp which fits all classes of pipe in each pipe size. In some cases, however, different gaskets are required for the different classes of pipe.

We have one or perhaps more leaks that we have been trying to locate for more than five years without success. At first we thought the water came from a spring (this still may be possible) but when checked for fluoride we found that it contained 1 ppm which is the amount we have in our finished water, while the natural fluoride content of the water in this area is at the most 0.35 ppm. The leaks show up in basements of business establishments and in the downtown section. These leaks are giving us a difficult time. We have used leak detectors, drilled, and dug, without success. We expect that someday we will run across an old service somewhere in the area which is giving us the trouble.

LEAK SURVEY

Leak survey is an extremely helpful tool in water distribution maintenance. Particularly if you should be so fortunate as to be able to assign a crew to the job or perhaps include it with the duties of the hydrant or valve operating crew.

The cost of hiring a leak survey party as such should be weighed against the cost of the unaccounted for water and the amount of the unaccounted for water you think that you can save. If you are billing for 85 per cent of the water you pump, then I would say keep an eye on it. If it should drop below the 85 per cent figure, then I would *consider* a leak survey. I would make this consideration after having carefully approximated the amount of water lost to main flushing, sewer flushing, street flushing, public fountains, and unbilled institutions. This, added to the allowable loss at joints in the system, will leave very little lost water if you bill for 85 per cent of the water you pump.

The equipment used in a leak survey consists of a microphone, earphones, amplifier, tone indicating dial, gain and volume controls.

In a survey we would start with the obvious situations; that is, the leaks which show up on the surface. The leak can be localized by taking readings on hydrants, services, or valves in the area and "moving" in on the leak. As mentioned before, the type of soil and backfill have a lot to do with the success of leak detection. When using leak locators we find that sound will travel up to 100 feet in sand and perhaps only five feet in clay. With the gain and volume set, so that the dial is in the halfway position, move the microphone from one position to another on each side of the assumed location of the leak, observing all the while the increase or decrease of tone on the dial. Naturally, an increase would indicate that you are closer to the leak. By drilling directly above the water main, a probe bar can be pushed down through the drilled hole to the water main and the "mike" attached to it and readings taken.

The principle of detecting a leak is to pick up and amplify the sound from the leak. This sound is made by the force of the water passing through the break in the pipe and has quite a constant hissing tone. The sound set up by the disturbance of loose earth around the pipe and near the break is that of sand rubbing against pipe, while stones rolling and striking the pipe intermittently give a dull scraping and striking sound.

One will also pick up the sound of the flow of the water within the main itself. This sound will vary inversely with the coefficient of flow and may even give you an indication of the condition of the interior of the main.

It takes an experienced operator to detect common sounds (such as the normal flow of water in the main, meter nutations, electric motors, ignition spark, and other distracting interferences) from the actual sounds set up by the leak. To keep these interferences to a minimum we find that the hours from 10:00 p.m. to 5:30 a.m. are the best. We also find that the "mike" must be attached securely, not held by hand, and must be protected from the wind. This will also eliminate many distracting sounds.

VALVES

Valves, as they appear to the casual observer, are nothing more than a manhole ring and cover or a roadway box and cover. But to you and to me they spell the difference between turning off the water to 40 customers in order to repair a break or turning off the water to 300 customers. It is hard enough trying to convince only 40 customers of the need for turning off the water in their block; when the customers are two, three, or four blocks away it is even more difficult — particulary if you have to tell them that there are valves in between that do not work because they were broken the last time they were operated. Suffice it to say, broken valves should be repaired immediately. Too much emphasis cannot be placed on having on record the location of each valve and the size of each valve. There should be some means to identify the rotation for opening a valve, if this rotation is different from your standard. If you use both right- and left-hand valves, I am sorry for you if you do not have the direction of rotation indicated in some way on each valve. Marking or tagging that will not stand the extremes of weather will be useless. If you use all roadway boxes, the only space left is the underside of the cover or the inside wall of the box. Marking the inside of the valve box cover or manhole cover is quite satisfactory, but costly and subject to confusion if the covers are changed or mixed with another cover. This, however, is unlikely. Another indicator for the direction of rotation would be to have hex operating nuts for one direction and square operating nuts for the other. This would require an additional operating wrench. We feel, however, that the best policy is standardization, i.e., have them all operate in the same direction.

Valves that give trouble should be first on your repair list, especially if they are on the main feeders and arterial mains of your distribution system. Any good valve will have sufficient identification on its body so that all necessary repair parts can be ordered and on hand before the repairs are started. You should know from the history of the system if the valve needs to be replaced or just repaired. Here is an excellent opportunity to change the rotation of the valve operation; that is, if you replace both the wedge or discs and the operating stem.

Since the advent of the "O" ring seal for operating stems, the packing problem should become less acute as time goes on. However, many of us still will find it necessary to replace packing from time to time. If you have only the roadway valve boxes, it is likely you will not repack a valve until the packing leak shows up on the surface. With valve manholes, repairs can be made without digging up the street. The valve manhole versus valve box controversy would require more time and space than can be allowed in this discussion. Suffice it to say, by now most of you know the type of cover you want to use to satisfy your conditions.

Special power valve operating equipment in several capacities and sizes is available from manufacturers. Some are gasoline driven, some by electricity, and some are driven from the power takeoff of a truck. With this type of equipment your crews can operate many more valves per day more easily. They can also do a better job because of the forward and reverse feature of these operators.

With this power-driven equipment we are able to operate all of our valves 12 inches and larger on an annual basis. This is very gratifying for both management and repair crews.

HYDRANT MAINTENANCE

Hydrant maintenance is an operation done either by the water department or the fire department. Most generally, however, it is done by the water department. One reason for this may be that the water department receives a rental charge each year for each fire hydrant which is returned to the city general fund in lieu of taxes. In any event, we feel that we are better equipped to maintain the fire hydrants.

If you are so fortunate as to have a crew assigned to hydrant and valve maintenance you can be quite certain that your hydrants will operate properly most of the time.

What do we mean by proper operations? First, the valve on the hydrant lead must be fully open. If you do not have valves on the hydrant leads you are in for some rough times ahead. Second, the hydrant should operate easily enough so that a fire fighter can open it and turn it off. If the hydrant is of the quick opening type the fire fighters should be cautioned about closing the hydrant down too quickly. Third, the valve in the hydrant barrel must be free of any imbedded foreign materials (which for the most part are stones and sand) which can prevent the valve from seating. Fourth, a loose valve or worn linkage in some hydrants will cause the hydrant to chatter and in some cases drive the hydrant off the lead if it has not been properly blocked or rodded. Fifth, in the parts of the country subject to freezing conditions, it is very important that the drip function properly; that is, so that it drains the barrel of the hydrant and closes when the hydrant is open. Sixth, the operating cap may be missing or broken or the operating stem may be all chewed up. These must be serviced. Seventh, the threads on the hydrant nozzle must be in the best of condition, i.e., good clean threads, a *thin* film of grease, and smooth edges and nozzle caps on every opening.

The following are suggested ways to service these in the event of improper operation. If the hydrant opens hard, look for hardened packing, lack of lubrication, or poor operating threads or a bent rod. If there is imbedded foreign matter in the valve, this may be blown out by the flow of water past the valve. If it can not, the valve must be replaced. Likewise, a loose valve or worn linkage must be replaced. If the drip does not drain properly, it may be that the parts are plugged or the dry well outside of the hydrant barrel is insufficient in size. We use a volume of at least four cubic feet in the dry well. Some hydrants are used quite frequently by the street crews. These hydrants often require new nozzles, when their threads are worn out, and new caps to replace those that are lost.

Since the fire hydrant is one of the very few parts of our distribution system that the public sees, we should make every effort to keep them in first class condition. This should be done for the sake of appearance and for fire protection.

The proper type of equipment for the handling of fire hydrants is of prime importance, both for better hydrant service and for the well-being of the men doing the work. We have experimented with several types of truck-mounted hoists and booms. We find that when we have a boom capable of handling a fire hydrant eight feet beyond the end or side of the truck, we needed a truck so large that it takes a ten-acre field to turn around in and that has power and space we will never use. As a result we find that a front end loader or a medium-sized tractor with a back hoe is very satisfactory and has many more uses.

Snow and freezing weather add their bit to hydrant maintenance problems. Consequently, we dispatch men to shovel the snow from around the hydrants and to thaw out frozen hydrants. Commercial steam generators of many sizes are available, some designed especially for hydrant thawing. Some operate on L.P. gas and some on fuel oil. We use the L.P. gas units. To keep the tanks from freezing we run the truck exhaust through a jacket around the tanks.

The fire department reports all hydrants that are used during freezing weather so that we can check them for draining.

We provide each of the police squad cars with a hydrant wrench so that the officers can turn off hydrants which have been opened by pranksters or that are being used without authorization.

A hydrant record card is an extremely handy source of information, especially when it lets you know the hydrant location, the location and position of the valve to the hydrant, the amount of water available from the hydrant, the number and size of connections, and the size of the lead pipe and main. Service dates and other information might be included.

Each of us has his own ideas about the painting of fire hydrants. These range from solid colors of all shades and hues to multicolored, coded and reflectorized.

Color coding is very helpful to fire departments, particularly in high-value districts. In applying code colors a hydrant is identified as being capable of delivering a certain volume of water or is connected to a particular size of water main. The National Board of Fire Underwriters recommends the following:

Class	*Flow*	*Color of Tops and Nozzle Caps*
A	1,000 GPM or greater	Green
B	500–1,000 GPM	Orange
C	Less than 500 GPM	Red

Fire hydrant repairs can be reduced by having strict regulations enforced on the use of fire hydrants for purposes other than fire fighting.

As far as maintenance is concerned, it is quite evident that color coding is considerably more expensive than solid colors. But it has its merits.

Now, in the interest of the health of the community served, I would be remiss if I overlooked the necessity of taking water samples from the distribution system daily to be tested for coliform. The recommended number of samples is established by your state board of health. This is protection for your water system and your community which you cannot afford to neglect.

One other matter I would like to call to your attention before I close is the need for a good inventory of parts necessary for repairs on your distribution system. At least some pipe and solid sleeves or couplings of each pipe size in your system in addition to some valves, hydrants, and fittings should be on hand. Then you should have a "stack" of repair clamps and sleeves of the required sizes and lengths. "Don't get caught with your clamps down."

In conclusion, I am convinced that the best and most economical way to maintain a water distribution system is to have well-trained and well-paid personnel, good records, good reliable equipment, a complete inventory of repair items, and, last but not least, a governing body willing to stand up and be counted in favor of providing the funds necessary to run a water works the way it should be run.

VALVES, HYDRANTS, AND MAIN LINE METERS

G. H. RUSTON[1]

MAIN LINE METERS

I would first like to touch on main line meters. I don't intend to get into the respective merits or faults of some thirty individual different manufacturers of meters or to delve too much into the various types. Mainline or master meters provide the means of determining total flow and are the basis for accurate accounting, chemical treatment, and to determine unaccounted for water.

Most meters are based on the velocity of water running through the meter which causes a differential of pressure between two points which is proportional to the flow, or the velocity of the water drives a propeller with the speed of the propeller being proportional to the flow. In recent years, a magnetic flow meter has been developed in which the flowing liquid moving in a magnetic field forms the moving conductor necessary to generate a voltage, which is proportional to the flow. Another type uses the linear displacement of a sound wave induced in a direction perpendicular to the flow.

The actual readings can be direct, at the meter, or remote by the use of mechanical or electrical devices and can both be visual and recording. The type of meter used should be based on the application; the size will depend on the flow to be measured. Needless to say, the installation of a 4-inch meter on a flow that requires an 8-inch meter will result in inaccuracy, excessive pressure loss through the meter, and excessive wear. A meter selected and engineered for the particular application in which it is to be used will do an excellent job, but it cannot be merely installed and forgotten. Like any other piece of equipment, it needs periodic attention and maintenance, and if this is done at regular intervals, the time involved and the cost will be nominal.

Why meters at all? It appears to me that from time immemorial man has measured water in some fashion, whether this measurement was ten double handfuls, three half coconut shells, or four bucketfuls a day from the nearest well or spring.

To operate a pumping station or filter plant intelligently, and economically, it is imperative that we know how many units, whether it is gallons or cubic feet filtered, are pumped, or used. Most sales of water are on a metered basis so it can readily be determined how much water is being paid for. Since these meters are at the point of consumption and we would like to know the amount of leakage, throughout the distribution system, it is important that we know how much water we have supplied to the distribution system for any given period. Water loss in the distribution system is pure waste water and is of no value to anyone.

With accurate main line meters and accurate meters at the point of consumption, the percentage of loss can be readily determined. What should this percentage of loss be in good operating practice?

The Wisconsin Public Service Commission reports reveal that in 1959 results from the 17 largest cities in Wisconsin showed that on the average 85.1 per cent of the water was being accounted for. This covered a low of 68.8 per cent to a high of 98.6 per cent. The average from the same cities in 1931 was 65.2 per cent with a low of 28.5 per cent and a high of 81.9 per cent.

This would tend to show that in 28 years the utilities are becoming more aware of costs and doing a better operating job. At least the figures reveal this trend. It appears to the writer that a figure of 85–90 per cent can and should be readily obtained. Without mainline meters, which are registering accurately, any figures are a mere guess.

The writer recently attended a hearing of the Wisconsin Public Service Commission in which the trustees of a small sanitary district desired to install water meters on the services of each of their approximately 125 customers. In presenting their case to the examiners the trustees attempted to show the tremendous water consumption per capita and that the installation of individual meters would cut this excessive consumption. On cross examina-

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tion the trustees had to admit that they had gotten their consumption figures in a round-about way as there was no mainline meter in the system. The source of supply was a well with a single pump. They had monthly power bills, which of course had been arrived at by an electric meter. They had gone to the pump manufacturer who had worked out a formula for so many gallons per kilowatt hour. They had a figure, but its accuracy was questioned because no consideration had been given to age of equipment, its efficiency, operating head, etc. So far, the Public Service Commission has not issued an order so the end result is not known.

The writer receives on his desk early each morning data pertaining to the previous day's pumping and treatment. These data include the low lift pumpage (the amount of water treated), the pounds of various chemicals used (which in turn, have been converted into dosages in parts per million based on water treated), and the amount of water pumped to the distribution system.

We have our filter and pump operators record meter readings hourly. This keeps them making the rounds and it also gives them an up-to-the-minute record of what the plant is actually doing. We know from practice what each pump should be delivering under given conditions, i.e., a 20 MGD pump theoretically should be pumping approximately 14,000 GPM. The hourly readings reveal what has hapened over the past hour and troubles are usually detected in advance.

The same holds true in the filtration plant where chemicals used are balanced against flow. Without mainline meters, no such records could be kept or, what is of far more importance, be of any use. Since these meters are all of the recording type, they are very useful years after the recording date.

The writer feels that accurate mainline meters that are kept that way are just as important as his watch.

VALVES

What are valves? Valves are mechanical devices by which the flow of water can be controlled from no flow to full flow. In a water distribution system, they are buried with the mains which in northern areas are located from five to ten feet below the surface. There must be some means of access from the surface to the valve proper so that it can be operated. If we had the perfect distribution system, one that never needed any maintenance or repair, there would be no need for valves. However, since we are still a long way from this ideal situation, valves are as necessary to a distribution system as are pipes or hydrants.

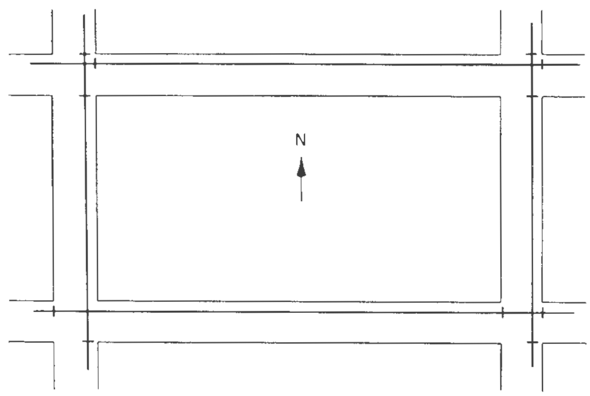

Figure 1. Typical valve location in Racine, Wisconsin

The water piping system should have valves at intervals. This makes it possible to shut off part of the system for repairs or extensions without putting large areas out of service. In general, the National Board of Fire Underwriters recommends that enough valves be provided so that no single accident, break, or repair will necessitate shutting down a length of pipe greater than 500 feet in other sections, and will not result in shutting down an artery. Racine's typical valving arrangement is shown in Figure 1.

An important factor in dealing with most interruptions to public water supply is the water utility's ability to operate valves in the system with a minimum of delay. This enables damaged areas in the distribution system or damaged facilities or equipment to be cut off so as to prevent needless loss of water and to maintain service in areas unaffected by the damage. A well-run water utility will have a good record of where all valves are located. They will also have a procedure for inspecting and operating each valve at least once a year. Too many water utilities do not have such records, and their valves are not inspected and tested with any degree of regularity.

The writer recalls an instance at Racine where good valve operation paid off. I am quoting from the records, in this instance, because a court case is involved. On the night of February 11, 1959, at 9:00 p.m., the water department received an emergency call from a certain address that excessive water was pouring into the consumer's basement. The temperature at this date was zero with about 3 feet of accumulated snow on the ground. The first evidence of trouble inside the house occurred at approximately 8:50 p.m. when the owner heard a sound of running water apparently in his basement. He went to the basement and found a horizontal crack about half way up the south wall of the basement (this was the street side) and water was entering the basement. The basement walls were of concrete block construction. He called the water department at 9:00 p.m. and a water department employee responded to the call, going first to the house. By this time the north and west walls had caved in. The electrical panel for the house was located on the north wall, and since the electrical clock had stopped at 9:05, this was undoubtedly the time when the north wall let go.

The water department employee's first thought was to close the curb cock on the presumption that it was a service leak. There was no evidence of any water on the surface of the street. The curb box was under a pile of frozen snow some 5 feet in depth. The water department employee abandoned this idea and proceeded to a valve on the distribution system. Fortunately the house was on a dead-end street and one valve would do the job.

To find the valve was a little chore. We locate our valves on street lines but this was in a newly built area with everything covered by snow. The truck was equipped with distribution system maps showing the location of the valve, and measurements had to be taken all by one man in the dark. He measured off and checked with his dipping needle which verified the location; pick and shovels got through the ice and located the valve box. The cover was frozen in place but a little antifreeze loosened it and the valve was closed and water off by 9:30 p.m., or thirty minutes after receiving the call and in spite of severe weather conditions. The leak turned out to be a broken 6-inch main in front of the house. There were some 48 inches of frost in the ground, and water never came to the surface but followed the gas service trench to the house and then saturated the earth on the outside of the basement walls. This earth was not frozen because of heat from the basement.

The owner claimed damages totaling $5,600. The department's insurance refused to pay on the grounds that there was no negligence on the part of the water department. The case is still pending.

Valves and their installation cost money, but they are worth their weight in gold to the operator when he needs them. Needless to say, if they are not maintained so that they are operative, they are worse than no valves at all.

The National Board of Fire Underwriters will give deficiency points on inadequate spacing of valves and inspection and condition of valves.

A wide variety of valves can be obtained, depending upon the type desired by the utility. Valves can be selected on the basis of the kind of metal, the type of pipe connections, or their means of operation (mechanically, hydraulically, electrically, etc.).

For years, distribution system valves have been of the gate type, with valves 16 inches and larger usually being horizontal and geared for ease of operation. The larger size valves are also generally equipped with by-passes.

In recent years butterfly type valves are being used in distribution systems. In the larger sizes they are usually cheaper, and since the pressure on the gate is balanced they operate easily.

Location of Valves

Valves should be located uniformly throughout the system in reference to street intersections, such as on property line, curb line, sidewalk line, etc., as these help tremendously in locating valves in emergencies. In Racine we locate our valves as shown on Figure 1. (On streets running north and south our mains are on the east side of the street and on streets running east and west on the north side of the street.) The valves are located at the extension of the street lines. Large wall maps showing location of main, valves, and hydrants are available, and each truck carries a book of the distribution system which shows actual measurements to the valves.

Maintenance of Valves

Valves should be operated and tested periodically so that they will work when needed.

We like to operate all valves once a year. The valve is run down and the turns counted. This gives a good check on whether or not the valve actually closes, i.e., a valve that should take 40 turns to close and the operator gets only 32 turns means that the valve has not seated. Naturally, in operating the valve, accessibility is automatically checked. If the operating wrench will not go on the operating nut the valve will have to be exposed and the box shifted. Any time we have a valve exposed it is repacked. In normal valve operation a packing leak may be started. If this is a small leak, the valve is opened all the way so that the collar on the stem is thrust up against the bonnet. In most cases this stops the leak. If the packing leak is severe, the valve has to be repacked.

Valves can now be obtained with "O" ring seals instead of normal packing. This practically does away with packing leaks.

Paving or resurfacing of streets places added work on the utility because the valve boxes must be brought to grade and maintained at that level until the new street surface is in place. This usually means that a Water Department employee must be present during the street surfacing operation.

Another important factor after the use of any valve, whether it be routine or an emergency, is to see that the valve is left open. I know of nothing more embarrassing than to find several valves closed while one is making a survey with the National Board of Fire Underwriters. This requires constant checking and rechecking together with rigid instructions to employees. A little routine maintenance will pay off.

HYDRANTS

Hydrants apparently have three prime functions:

1. Focal point for every dog in the neighborhood.
2. Target for drunken drivers out after 2:00 a.m. on a cold Sunday morning.
3. An instrument for providing water to put out fires.

I will devote my remarks to this latter function although it has been our experience that hydrants are being used less and less for putting out fires.

A hydrant is merely a device for obtaining large quantities of water easily and quickly from the underground main of the distribution system. Thus they must have inherent in their construction a valve mechanism that will control the flow of water. This mechanism must be simple in operation yet rugged in construction so that it can take abusive use. Most hydrants have this valve at the base, many feet below the surface of the ground. In Wisconsin, due to frost conditions, this is 6 feet or more. The valve must be operated from the top so that it is readily accessible to firemen. The top, or the portion above ground, must be fitted with nozzles or some device with threads or clamps so that the fire hose can be attached quickly and firmly.

Most hydrants today have two nozzles, approximately 2½ inches in diameter, for attaching the regular fire hose plus a pumper or steamer nozzle. This nozzle is generally about 6 inches in diameter. This serves as the suction for the pumper if the firemen desire to increase the pressure. When these outlets or nozzles are not being used, they are protected by caps. Whether these caps should be attached to the hydrant by chains to keep them from being lost is a subject in itself.

The barrel, or vertical pipe, of the hydrant varies from 4 to 8 inches in diameter. The larger size, of course, carries more water. Naturally, the hydrant has no magic properties and cannot furnish more water through its outlets than that available in the main or hydrant lead to which it is attached.

Hydrants, like valves, can be furnished for any type of pipe connection, i.e., for cast iron pipe (bell and spigot, mechanical, or slip-on joints) or for steel, concrete, or asbestos-cement pipe. "O" ring seals are very popular, and some hydrants can be furnished with ball bearings for ease of operation.

The National Fire Protection Association specifications for fire hydrants are "that hydrants should be able to deliver 600 GPM with a friction loss of not more than 2½ p.s.c. in the hydrant and a total loss of not more than 5 p.s.c. between street main and outlet; they shall have at least 2–2½-inch outlets, and also a large pumper outlet where pumper service is necessary. Hydrants must be of such design that if the hydrant barrel is broken off the hydrant will remain closed."

Hydrants that are designed so that the hydrant valve works against the pressure do this very nicely, because the water pressure tends to keep the valve closed.

The hydrant should be provided with some draining device so that the water left in the barrel of the hydrant can drain off readily and cannot freeze in the hydrant, thus rendering the hydrant useless for future use.

In Racine a representative of the water department goes out on fire runs where water is used from hydrants. He checks each hydrant after operation to see that the hydrant is closed, water has drained, and caps have been replaced. Should the hydrant

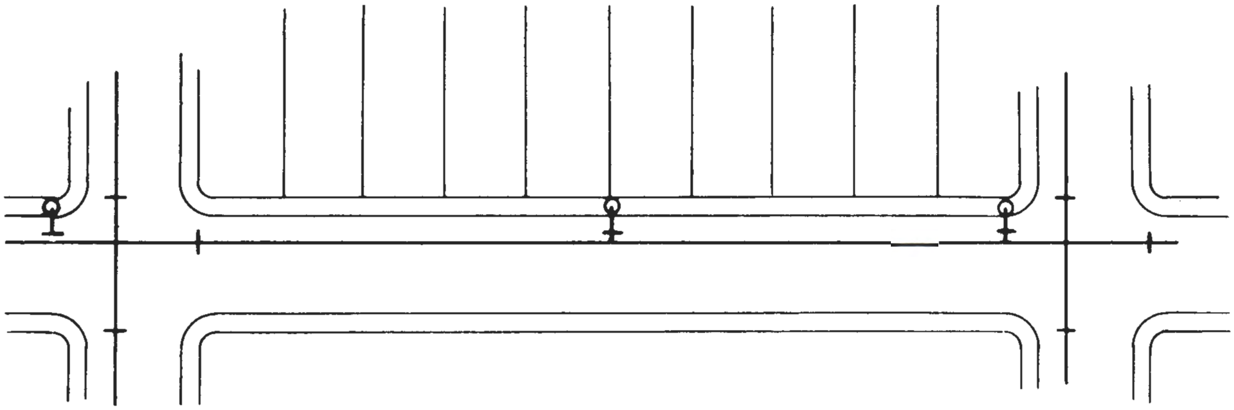

Figure 2. Hydrant locations in Racine, Wisconsin

fail to drain, it is pumped out immediately, because freezing will occur very fast in sub-zero weather.

Hydrants, like any other piece of equipment, no matter how well designed and constructed, should be regularly maintained. In Racine all hydrants are checked annually to see that they will open, close, drain, and that the threads on the nozzles are in good condition. These inspections will reveal that in some locations the hydrants need repair. These repairs are done promptly and the work done is noted on the hydrant card. If the hydrant will not function at all, the fire department is notified at once. It is again notified when the hydrant is operative. In certain locations, the hydrants will not drain because of the ground water level in the area. These locations call for special treatment. The drain can be permanently closed so that no ground water can seep into the hydrant. This means that during winter months, the hydrant must be pumped out after each use to prevent freezing. In some cases, where the ground water can't be eliminated, this method has to be resorted to.

Spacing of Hydrants

Hydrant spacing and location is another important aspect. In general, hydrants should be placed with consideration of their possible use as reflected in the local hazards. Hose lines more than 400 to 500 feet long are inefficient and a source of delay. Therefore, hydrants should not be distributed more than 300 to 400 feet from the buildings to be protected. Furthermore, friction losses use up pressures available in hose lines at a rapid rate, and this factor definitely limits the length of hose lines. Where it is fire department practice to use hose lines direct from hydrants, pressures available are seldom more than 100 pounds. Under these conditions lines must be kept shorter by several hundred feet than in the case of lines from pumpers in order to prevent undue friction losses. This means that under such conditions hydrants must be spaced about 100 feet closer together.

If hydrants are widely spaced (i.e., 500 feet or more) the effective capacity of pumpers is reduced because of the higher pressures at which they must deliver. A rough rule to follow is to place one hydrant near each street intersection and to set intermediate hydrants where the distance between intersections exceeds 350 to 400 feet.

In Racine, our blocks are about 300 feet one way and 600 feet the other. Hydrants, as shown in Figure 2, are placed at each street intersection and in the middle of the block of the 600-foot length. The hydrants are placed within the lines of the street right-of-way so that the hydrant nozzle toward the street is 6 inches behind the face of the curb. This permits easy access for the fire department. It also places the hydrant fairly close to the travelled area of the street and thereby makes a good target for a car out of control. The hydrants at the intersection are located at the beginning of the curve of the curb.

The location of the hydrant in the middle of the block is always a problem. The ideal thing would be to have the hydrant on wheels. Every property owner wants the hydrant close by so that he can get the lower insurance rate. However, don't put it in front of his house! We place these hydrants in the same location from the curb and on the line with the property line between the lots. The owner of one of the lots will invariably place his driveway adjacent to this property line. The obvious result is that sometime during the year he will come in contact with the hydrant — with his car coming off second best. He immediately wants that damn hydrant moved!

Our policy has been to move the hydrant if he will pay half the cost ($100–$150) and if he will find a neighbor who has no objection to the new location. The one-half cost provision generally stops the proposed move.

Sooner or later a hydrant has to be taken out of service for major repairs, such as for a new washer on the gate. If an auxiliary valve has been placed on the hydrant lead, this work can be accomplished without putting any customer out of water, and it also serves as a means of controlling the flow if a hydrant is damaged or leaks.

Supervising Use of Hydrants

It is important that the water department and the fire department work out a joint procedure to prevent hydrants from being damaged through misuse. The most practical arrangement usually is to require that the fire company, to which a hydrant is assigned, be notified whenever it has to be used other than for fire purposes. There will be situations where the water department will permit building contractors or others to take water from hydrants for some temporary purpose. The water department and the fire department should agree on a general practice with respect to such use of hydrants. The water department must know about the use of water to prevent abuses and to make charges for the water. They may wish to require contractors to post a bond or cash to take care of possible damage.

The water department should require that fire department permission also be secured. It is the fire department's responsibility to see that the use made of the hydrant is not such as to interfere with fire department requirements. They have a further responsibility to prevent damage to the hydrant through improper operation. For example, a contractor should have the proper wrenches to operate the hydrant nut. He should be prohibited from using ordinary pipe wrenches. The contractor could be required to obtain from the fire department a proper hydrant wrench before turning on the hydrant. This procedure enables the fire department to see that the hydrant is properly used, which is particularly important in freezing weather.

In Racine, during the summer months contractors are often working on curbs and gutters, street pavements, street flushings, etc. and water is needed on the job. The water department, after proper application, places auxiliary valves on one of the 2½-inch outlets, and the hydrant valve is opened and left open. The contractor uses the small auxiliary valve controlling water from the hydrant. All the wear and tear is then placed on this valve. The fire department is aware of hydrants so equipped. If they use these hydrants the firemen must first close the main valve before they can attach their hose. Although this will somewhat slow up their use of the hydrant, the arrangement works very well. A charge is made to the users of these valves.

The water department furnishes the fire department with maps of the distribution system, showing locations of the hydrants and the sizes of mains. The water department annually conducts a school (generally over a five-day period) so that each fireman, old and new, is in attendance for one session. Working models of actual types and makes of hydrants in the system are demonstrated at these sessions and mutual problems discussed and solved. Attendance at these schools is a "must," and the fireman attends while he is on duty so he is not giving up his time.

During the winter, after prolonged snows, many of the hydrants, especially at street intersections, get covered up. Help is obtained from Boy Scout Troops, appeals to citizens by press and radio, and actual removal of snow by water department employees.

Finally, although the hydrant is no thing of beauty, its appearance can be improved by painting. This painting can be done elaborately by using different colors, or it can be done simply by using one color. Hydrants can also be identified by use of different colors to denote flow.

Who pays for the hydrants? In Racine the Public Service Commission allows the utility 10 cents per foot of pipe (6 inches and above) plus $15.00 per hydrant which is paid by the general city out of tax money.

DOMESTIC SERVICE METERS

A. R. Moore[1]

Water meters commonly used for household, commercial, and industrial services include the *positive displacement, velocity, compound*, and *fire line* meters. Velocity meters include the *current* or *turbine* type employing a hard rubber impeller, and the *propeller* type, employing a propeller made of plastic or other material.

Positive displacement meters incorporate an "interior," or "chamber," with a hard rubber disc or piston which oscillates or nutates, producing rotary motion in a drive spindle connected by gearing to the meter register. For each complete cycle of the disc or piston, a volume of water equal to the volume of the chamber (less that of the disc or piston) is displaced. These meters, in $\frac{5}{8}$-inch sizes, with $\frac{1}{2}$- or $\frac{3}{4}$-inch threaded spuds, are commonly used for household services. Larger sizes up to 6 inches may be used on commercial services. With increasing residential demands, due to greater use of clothes-washing and dish-washing machines, lawn sprinkling systems, and garbage disposers, greater use is being made of full $\frac{3}{4}$-inch meters for household use.

In recent years, a new style of positive displacement meter has been introduced featuring a magnetic drive. This type eliminates the stuffing box on the conventional meter, and the intermediate gear train and register operate in sections sealed from the water. Thus, service calls are reduced and lower maintenance costs and longer service life are realized.

The current or turbine meter in 2- to 12-inch sizes is inherently inaccurate at low flow rates. Thus, its use is normally limited to applications where low flow accuracy is not of paramount importance. In applications where higher, steadier flow rates are normal, these meters will give longer service life before new parts are required than will the positive displacement meter.

The propeller type of velocity meter may be considered a mainline meter, although it has found wide commercial application in metering irrigation systems. In addition, it has been used in other specialized applications.

Compound meters in 2- to 12-inch sizes combine a positive displacement meter and a velocity meter, usually the turbine style. Construction may incorporate both meters in a single case or they may be in separate cases connected by suitable fittings. They are used where low flows and wide variations in flows may be frequently encountered. A valve mechanism diverts the flow to the velocity meter on higher rates, with flow through the positive displacement meter continuing or stopped, depending on the design. Typical applications are apartment buildings, institutions, office buildings, and domestic or process services in factories. Usually, compound meters are preferred to *disc* meters on 3-inch and larger installations. If fire protection is required, a separate fire line should be installed.

Fire line meters in 3- to 12-inch sizes are especially designed for low friction or head loss. These, like the compound meter, incorporate a main line and bypass section. The bypass section employs either a disc or compound meter. The mainline section employs a current or disc meter operating on the proportional principle. At higher flow rates, a valve opens to permit operation of the mainline section. These meters are used on fire lines, on combined domestic and fire line services, and as master meters on distribution systems.

The importance of properly metering all services cannot be overemphasized. We are witnessing a tremendous growth in population in the United States. Water shortages have become severe on the West Coast and are developing in many areas where water has been plentiful until recently. Water consumption is also greatly influenced by expanding industrial use and increased per capita use. A very thorough survey, made in the past year, of consumption trends indicated an increase from 134 gallons per day per capita in 1960 to 170 in 1970.[1] This is an increase of almost 27 per cent in ten years.

[1] Engineering Assistant to Sales Manager, Hersey-Sparling Meter Company, Dedham, Massachusetts.

As a result, conservation of water has become vitally important, yet no water department can account for all water used. Distribution losses can occur in more than 30 ways, including leaks in mains and fittings, use of unmetered water for system maintenance, use for municipal purposes and losses from inaccurate meters.[2] To reduce these losses, modern leak-detection methods are being increasingly employed. Metering every user of water, including all municipal departments and contractors drawing water from hydrants, will help materially. In addition, the proper maintenance of water meters will pay substantial dividends. This is a particularly critical area, because inaccurate meters can mean very substantial revenue losses. Among the many benefits of a good meter maintenance program are: conservation of available water, reduction of water consumption, and elimination of water waste. Large expenditures for unneeded mains, pumps, treatment facilities, and other equipment can be eliminated and daily operating costs reduced.

Before discussing recommended maintenance practices, mention should be made of meter ownership and installation practices. These vary widely.

In many municipalities, the water department purchases and installs all meters at no charge to the consumer. In others, the water department may purchase and install the meter, but the customer pays a meter and installation charge. In other municipalities, both purchase of the meter and installation are the responsibility of the user, with specific standards set up by the water department to which the user must comply. Meters may be installed on municipal property at the property line or they may be installed on the customer's property with title held by the municipality.

The determination of a particular meter size for various service categories may be based on rule-of-thumb, or practical experience, or even on mathematical approaches. For example, one large city specifies $\frac{5}{8}$- x $\frac{3}{4}$-inch meters for homes and apartment buildings with up to three apartments, $\frac{5}{8}$-inch meters for small offices and warehouses with up to three washrooms, and 1-inch meters for apartment buildings with three to eight apartments. Other meter sizes will only be considered if fixtures indicate excessive demands. Standard meter sizes are established for most common applications to avoid recalculation and to permit decision making at lower levels of responsibility. For 3-inch and larger services, only compound or fire line meters are used. For the largest installations, the architect or consulting engineer specifies the meter size.[3]

Another interesting approach is based on the use of values or "fixture units" assigned each plumbing fixture in a house or apartment. These may be based on figures set up by the National Bureau of Standards. Thus, a total theoretical flow is obtained which is required for that particular service. Other factors taken into consideration in determining the proper service or meter size are (a) minimum main pressure, (b) difference in elevation between service line and highest fixture elevation, (c) meter pressure loss, and (d) distance from street main to farthest fixture. This approach has been found valid in one major system for standard conditions. For special conditions, local plumbing codes govern designs.[4] As an indication of the diversity of opinion on this subject, at least one other large water department (to the writer's personal knowledge) objects to this approach because it has resulted in considerably higher theoretical flows than experience indicates actually occur.

Recording instruments are available which can be fitted to a meter in place of the register. Depending on the make, either a strip or circular chart inscribed by a moving pen records fluctuations and flow rates for 24 hours, or for longer periods up to 30 days. These devices may also indicate total consumption as well as flow rate. If necessary, the meter can be changed to another, more proper, size based on the analysis of the flow chart.

Meter installations and meter design vary, depending on the size and type of meter as well as the section of the country involved. In colder areas, positive displacement meters may be equipped with a cast iron bottom which breaks out when freezing of the meter occurs, or they may have a breakable bronze bottom or one with provision for its release when ice forms within the meter. Thus, damage to working parts is prevented. Where no possibility of freezing exists, as in heated locations, or in southern climates, a split-case all-bronze style may be used.

Because of the possibility of freezing, household meters in northern areas are commonly installed in the basements of homes. Larger positive displacement meters for commercial services usually are installed in heated locations. On the other hand, compound, velocity and fire line meters are normally installed in pits below ground level outside the buildings they service. This does not, of course, preclude installation within buildings.

Because repairs or changes can be made quickly, household meters are not normally equipped with a bypass to provide uninterrupted service. On commercial or industrial services, this is usually essential. In typical installations, a gate valve is provided on both the inlet and outlet of the meter. One or two gate valves with a drain cock between them are also provided on the bypass line. In case of field test and repairs, the bypass valve would be opened, and the inlet and outlet gate valves connected to the meter would be closed so that no water could flow into the meter from either direction.

Because of their weight and size and the fittings involved, larger disc, compound, velocity, and fire line meters cannot easily be removed from their installations. These are normally repaired and tested in place. For test purposes, an outlet plug may be provided on the meter itself, to which a test meter is attached by means of fire hoses. This is a specially calibrated current meter which may be provided with a disc bypass meter for lower flows. Quick-closing valves and reset registers facilitate accurate measurement of precise quantities. Registration of the meter under test is checked against that of the test meter.

In field testing a meter, the outlet gate valve is closed and the inlet gate opened to allow water to pass through the meter to the test meter. Readings on the meter at the time of test are taken so that the meter registers may be reset after testing to avoid charges to the customer for water used. Provision must, of course, be made for the discharge of water from the test meter to a nearby sewer.

One test is made before any repairs are attempted to determine the condition of the meter. An experienced crew can gain an accurate idea of any malfunctions by analysis of this test. If necessary, repairs are made and then the meter retested. The larger meters in common use, such as 6-, 8-, and 10-inch compound or fire line meters, should be tested frequently because of the revenue involved. If extremely heavy flows are normal, test and repairs are advisable as often as every three to four months.

Except for the larger sizes (3 inches and above) positive displacement meters are normally removed from service and repaired in the meter shop. Frequency of repairs should increase with meter size, due to larger volumes of water being measured and increased revenue involved. A ten-year cycle for ⅝-inch meters has proven by experience to be a good starting point. However, based on local conditions, this period may be increased or decreased. In addition, intervals may be based on registration and other factors; for example: 100,000 cubic feet or 1,000,000 gallons, whichever comes first. All meters may also be removed and tested in some departments whenever property is sold and vacated. Other considerations include the effect of corrosive water, silt, or sand on meter performance (which may in some areas require more frequent repairs).

In addition, removal and repair cost must be balanced against expected gains in revenue. If meters are removed too frequently (particularly small meters) cost may be greater than revenue. However, lost revenue (particularly on large meters) may greatly exceed repair costs if repairs are not made often enough. Incoming test results or the extent of repairs required after various lengths of service provide a good guide on which to base a schedule. American Water Works Association publication "Tentative A.W.W.A. Standard for Cold Water Meters--Displacement Type," A.W.W.A. C700-61T, suggests intervals between tests for various sizes of disc meters, under average conditions. State Public Utility Commissions in many states also specify intervals between tests for each meter type and size which must not be exceeded.

A number of water utilities have made detailed studies to determine optimum periods between tests. One study was based on a mathematical analysis and resulted in an optimum period for this user of 14 years for ⅝-inch meters. However, the comment was also made that local conditions could definitely influence this interval.[5]

As far as actual meter repairs are concerned, some larger departments have carefully analyzed their repair methods and set up production lines in some cases, with conveyors, particularly for ⅝-inch meters. Parts which require repairs are set aside, and rebuilt parts or sub-assemblies are used to save time. Repairs on these sub-assemblies are then done separately. In smaller departments, if time is available, complete repairs are made on each meter in turn.

As a first step, a tag is prepared and attached to properly identify the meter. Space is provided on this tag for listing the parts used, the test results, and in some instances, the cost of parts and the time spent on repairs. The meter case is then cleaned with a wire brush to remove loose dirt. If repairs are not to be made immediately, it is advisable to fill the smaller meters (5/8-inch to 1-inch) with water and to cap the spuds so as to prevent deposits from hardening.

The next step is to give the meter an incoming test. There is great variation between departments on rates of flow, volumes run, and accuracy required. The American Water Works Association in its publication "Tentative Recommended Procedure for Testing Cold Water Meters," A.W.W.A. C705-57T, has outlined tests for positive displacement, current and compound meters which can be used to test new meters and repaired meters. These have been prepared in an effort to standardize tests in water departments, although manufacturers' recommendations may vary somewhat from these.

Some departments feel a minimum flow test is not important on the incoming test, since most meters requiring repairs will be inaccurate at this rate, will not be repaired to more than 90 per cent accuracy at this rate, or will require excessive time. Tests would be made on intermediate and higher rates to get an idea of the meter's condition and for record purposes.

The next step is disassembly of the meter and cleaning of meter parts, preferably at a separate meter bench or location. This confines dirt to one area of the shop and helps to keep the repair bench as clean as possible. A sloping cleaning bench equipped with a sump or double-bottom sink to catch dirt and foreign material is advisable. Hot and cold water and a short hose to wash dirt from meter parts and to clean the sink should be provided.

Plain water or ordinary household detergents may be all that is needed. If deemed necessary, alkaline and acid cleaners can also be used. For case cleaning, sand blasting can be used. For interiors, trains, and registers, equipment using fine glass beads in dry form or in a water-based slurry can be purchased. Recently, ultrasonic cleaners have been introduced.

Use of acids and alkalies is generally considered necessary where corrosive deposits build up, particularly in areas such as southern California where this is a common occurrence. Alkaline detergents are most effective on soil, grease, and paint. These usually require heating to 160° F. or more.

Another class of detergent, known as "emulsifiable solvent detergent," is effective on heavy soil such as carbonized grease and oil deposits. This solvent requires no heating and may be used as a pre-cleaner to lengthen the life of the regular alkaline solution. These detergents may be diluted in water or petroleum distillates.

Acid detergents are particularly effective on rust, tarnish, scale or other corrosive deposits. These detergents, normally supplied in liquid form, may be applied as they come or they may be diluted in water. Some are inhibited to prevent attack on the cleaned metal, the inhibitor forming a protective film.[6]

Ventilation is an important requirement if commercial alkalies and acids are used. Inhibited acids and specialized detergents may not require ventilation or other precautions necessary to avoid skin burns or damage to parts from excessive exposure to the cleaning material.

After cleaning, meters are ready for repairs. These repairs may be made either at a separate repair bench or where the meters are cleaned. Specific repairs required depend, of course, on the length of service and the make of meter. Parts normally requiring inspection are: the interior or chamber (with its disc or oscillating piston), the intermediate gear train, and the register. Worn or corroded parts are replaced and the meter reassembled for final test. After this test, which should be recorded, meters are sealed and stored before reinstallation. Storing positive displacement meters upside down is advisable to keep the chamber dry and to prevent the possibility of oil leaking from the intermediate gear train into the interior or chamber.

For most repairs on positive displacement meters, available hand tools are usually sufficient, although a number of special tools and gauges have been provided by manufacturers to facilitate certain operations. A drill press and combination bench grinder and buffer are extremely useful. Larger shops may employ impact wrenches, paint spray booths, power-operated cleaning equipment, and air compressors. Even for the smaller shop, meter testing machines are advisable for accurate volumetric testing of new and repaired meters.

Meter records may include a master file card for each meter, giving information on its make, size, serial number, cost and date of purchase, reading, addresses where installed, repairs required, and other pertinent information. Repair tickets and test records are used in the meter shop to provide an accurate record of test, material use, and cost of repairs. Other records include work orders for field crews inspecting or removing meters, and identifying tags for meters undergoing repairs.

A carefully prepared, consistently followed, meter repair and maintenance program will pay big dividends. Conversely, inaccurate meters mean substantial revenue losses. For example, with a charge of $1.20 for the first 4,000 gallons and 25 cents for each additional 1,000 gallons, an unregistered 1/4 GPM leak results in a yearly loss of $33.05, with 131, 400 gallons unregistered.

Losses from larger meters can be even more impressive. For example, with the same water rate (or charge), 90 per cent accuracy in a meter operating at 100 GPM, 12 hours per day, could result in an annual loss of $558.65 or lost registration of 2.233.800 gallons!

Further information on this general subject can be found in many articles published in the *Journal of the American Water Works Association*. From time to time, interesting articles appear in water works trade magazines. Manufacturers have also prepared manuals on maintenance for particular makes of water meters.

Recent developments in water meters and accessories (in addition to magnetic drive meters) have included electrically operated electro-magnetic meters, rate demand meters, sealed registers, and remote reading equipment. Magnetic drive meters apparently are gaining wide acceptance. As time passes, each specialized meter or device finds a generally recognized niche in the overall area of possible applications.

Manufacturers' publicity and educational efforts by trade associations and groups definitely affect the level of acceptance. On the whole, mechanically operated meters (actuated by the movement of water through them) probably will always predominate in number. This is primarily due to their relative simplicity, low cost of installation (particularly in the case of household meters), and absence of need for external sources of power.

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6. "Metal Cleaning and Surface Treatments," New York: Oakite Products, Inc. (1961), pp. 3–5.

7. Fred S. Porter, "Long Beach Meter Repair Shop and Testing Facilities," *Journal American Water Works Association,* Vol. 47, No. 2 (February 1955), pp. 111–120.

PROGRAM

Tuesday, February 13

8:30 a.m. Registration: *R. K. Newton*, Foyer, First Floor, Bevier Hall

MORNING SESSION: *O. S. Hallden*, Presiding; Room 180, Bevier Hall

10:00 a.m. Welcome and Introductory Remarks: *C. W. Klassen* and *N. M. Newmark*

10:30 a.m. "Hydraulics of Water Distribution Systems": *C. W. Reh*

11:30 a.m. "Applications of System Analyzers: A Summary": *M. B. McPherson*

12:30 p.m. Luncheon, The Spice Box, Second Floor, Bevier Hall

AFTERNOON SESSION: *R. E. Speece*, Presiding; Room 180, Bevier Hall

1:30 p.m. "Pipe Materials, Coatings, and Joints for Water Distribution Systems": *H. H. Benjes*

2:30 p.m. "Water Main Laying": *G. T. Watson*

3:30 p.m. "Tapping, Disinfection, and Inspection of Water Mains": *R. A. Wilford*

EVENING SESSION: *B. B. Ewing*, Presiding; Motel Urbana, Urbana

7:00 p.m. Dinner

8:00 p.m. "Public Relations": *J. E. Kleinhenz*

Wednesday, February 14

MORNING SESSION: *J. T. O'Connor*, Presiding; Room 180, Bevier Hall

8:30 p.m. "Observing Fire Protection Requirements in Future Water System Design": *A. H. Gent*

9:30 p.m. "Water Main Cleaning and Relining": *J. A. Frank*

10:30 p.m. Coffee Break, Cafeteria, Second Floor, Bevier Hall

11:00 a.m. "Maintenance of Water Distribution Systems": *J. M. Rogeven*

12:00 noon Luncheon, Spice Box, Second Floor, Bevier Hall

AFTERNOON SESSION: *G. E. Margrave*, Presiding; Room 180, Bevier Hall

1:00 p.m. "Valves, Hydrants, and Mainline Meters": *G. H. Ruston*

2:00 p.m. "Domestic Service Meters": *A. R. Moore*

2:30 p.m. Adjourn

Speakers

Mr. H. H. Benjes, Department Head, Civil Engineering, Black and Veatch Consulting Engineers, Kansas City, Missouri

Mr. William J. Downer, Chief, Bureau of Public Water Supplies, Division of Sanitary Engineering, Illinois Department of Public Health, Springfield, Illinois

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